Passage of Adult and Juvenile Salmon Through Federal Columbia River Power System Dams

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NOAA Technical Memorandum

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National Oceanic and Atmospheric Administration
U. S. Department of Commerce

June 2004

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INTRODUCTION

This Technical Memorandum synthesizes available information on the behavior and survival of juvenile and adult Pacific salmon (*Oncorhynchus* spp.) during passage through eight dams operated by the U.S. Army Corps of Engineers on the lower Snake and Columbia Rivers (Fig. 1). These eight dams and their reservoirs constitute the mainstem component of the Federal Columbia River Power System (FCRPS). This synthesis focuses on those aspects of passage considered relevant by NOAA Fisheries for judging FCRPS impacts to specific salmon stocks listed under the Endangered Species Act, and in general, to all salmon stocks in the Columbia River that utilize habitats within or above the FCRPS.

The amount of information developed through studies conducted over the past 60 years is large and reporting all the available information is beyond the scope of this document. The Memorandum focuses primarily on information gathered under contemporary conditions, or as the dams have been configured and operated since the 1995 FCRPS Biological Opinion was implemented. Results from studies conducted earlier than this time frame are discussed for context. The focus is on passage issues associated with the dams as they exist, not effects on salmon that might accrue from major changes such as dam removal. Nonetheless, it is recognized that many of the adverse impacts from FCRPS dams on salmonids would be reduced or eliminated with removal of dams.

The eight dams form back-to-back reservoirs over what was once a free flowing riverine ecosystem. This stretch of river constitutes important habitat that salmon have adapted to and use for spawning, rearing, physiological development, preparation for seawater entry, growth, and shelter from predators. There is no doubt that this complex of eight dams and reservoirs has significantly changed this riverine ecosystem and affected the stocks of salmon that use and migrate through this habitat. The effects of the FCRPS on listed salmon Evolutionarily Significant Units (ESUs) and potential benefits to these populations from actions undertaken in the hydropower system are being addressed elsewhere, such as in the complementary Technical Memorandum titled “Effects of the Federal Columbia River Power System on Salmon Populations,” through life cycle modeling, and through technical deliberations of the Technical Recovery Teams. Here we present what is known about passage at the concrete under current conditions to provide a source of information that can be used by hydropower system and resource managers to judge actions and make decisions regarding dam operations and configurations in the future.

As pointed out by the National Research Council, the long-term persistence and productivity of salmon populations are dependent, in part, on maintaining conditions that allow salmon to retain their genetic variability and local adaptations (NRC 1996). More recently, a viable salmonid population has been defined as an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame. Four key parameters are considered when evaluating population viability status: abundance, population growth rate, population spatial structure, and diversity (McElhany et al. 2000). It is not possible at this time to assess potential impacts to the viability of salmon populations from specific dam operations or configurations. Perhaps this question will be addressed in the future when appropriate data are available to make such an assessment. For now, we simply recognize that factors believed to be important to the viability of salmon populations over time have been identified and are an important consideration in recovery planning.

While this Technical Memorandum provides a review of available literature and pertinent information, the strengths and weaknesses of methodologies and data, and conclusions regarding specific fish passage issues, it does not offer conclusions regarding how dams should be configured or operated in the future - we leave that to decision makers who will be using this information to develop a new Biological Opinion for the FCRPS.

Finally, an earlier draft of this Memorandum was significantly modified to reflect comments and additional information provided by the Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game, Fish Passage Center, Bonneville Power Administration, Columbia River Inter-Tribal Fish Commission, and Save Our Wild Salmon. We greatly appreciate the time and effort contributed by personnel from these organizations to improving the content and usefulness of the Memorandum.

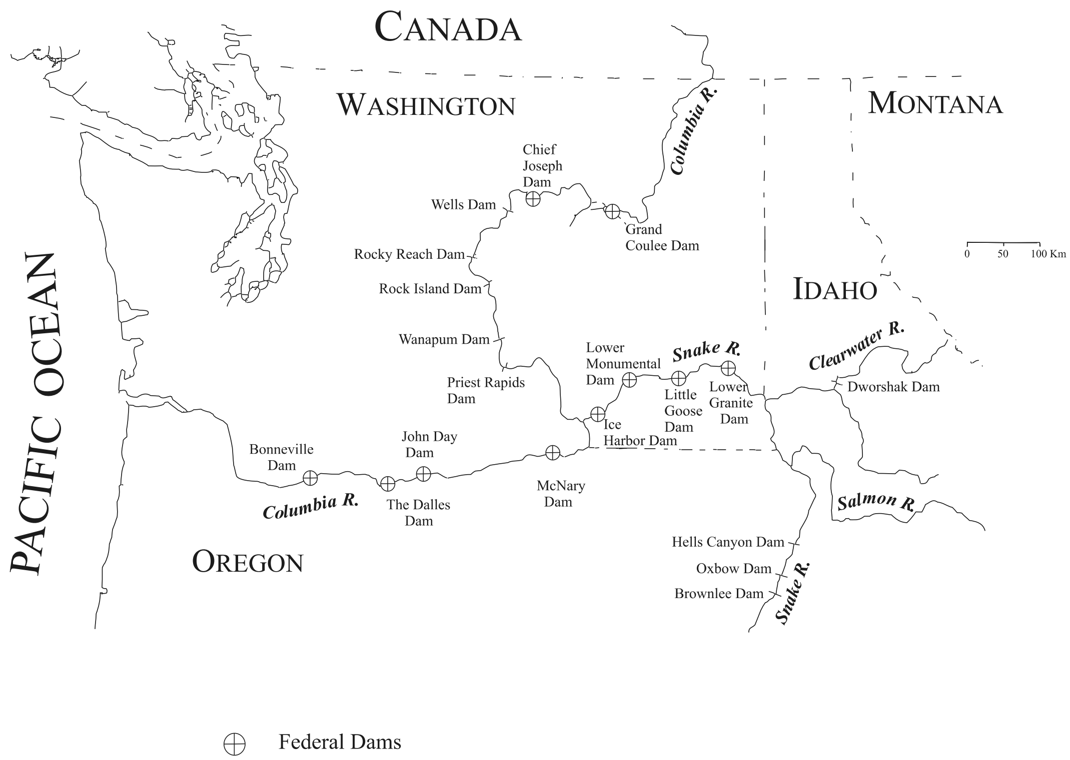

Figure 1. Federal Columbia River Power System.

JUVENILE SALMON PASSAGE THROUGH SPILLWAYS

Background

Downstream passage through spillways at major hydroelectric dams in the Columbia River Basin has been provided for many years to increase survival of juvenile salmonids. Historically, spill occurred operationally when project capacity or FCRPS generation needs were exceeded. However, as the hydroelectric system was developed, spill became less frequent. In 1988, a 10-year spill program under a Fish Spill Memorandum of Agreement was implemented to provide spill at projects to meet regional goals for fish passage through non-turbine routes. Continued declines in salmonid populations prompted the eventual development of the more aggressive spill management plans required under the NMFS FCRPS BiOps. Since implementation of the 1993 and subsequent BiOps, spill has generally been provided in accordance with the prevailing spill program in most years, but there has been considerable variation in spill among years for a variety of environmental (river flow), system (excess generation spill, excess hydraulic capacity spill, turbine failures, maintenance-related conditions), and fish research (test schedules) reasons.

The generally recognized benefits of spill include reduced mortality, migrational delays (through forebays, tailraces, and reservoirs), and exposure to predation risk, high water temperatures, and diseases (Whitney et al. 1997, Muir et al. 2001a, Giorgi et al. 2002). Previous studies have found that passage survival for juvenile salmonids at Columbia and Snake River dams is generally highest for spillways, followed by bypass systems, and then turbines (Schoeneman et al. 1961,Whitney et al. 1997, Muir et al 2001a).

The spillways of all FCRPS dams consist of a forebay, spill gates, ogee, stilling basin, and tailrace. The forebay typically consists of about 1 km of reservoir immediately above the spillway gates. Most spillway gates are a radial design with a 60-ft radius and 50-ft width (COE 1996b). Two dams (Bonneville and McNary) have vertically operated lift gates of similar width. Number of spill bay gates per spillway varies from 8 to 10 at lower Snake River dams to 18 to 23 at lower Columbia River dams. The ogee sections transition flow from below the gates to the stilling basin.

Flow deflectors that help reduce dissolved gas production are located on the ogee sections at elevations designed for each project. Below the ogee, the spilled flow enters a stilling basin designed to dissipate turbulent energy in a confined, armored zone, thereby minimizing the threat to the spillway's structure. Beyond the stilling basin, the tailrace extends for about 1 km downstream. Spillway capacities are designed for the maximum probable flood and vary from 850 kcfs at lower Snake River dams to 2,290 kcfs at lower Columbia River dams.

Research Results and Discussion

Spill Efficiency and Effectiveness

Spill efficiency is the proportion of fish approaching a project that pass via the spillway. Spill effectiveness is spill efficiency divided by the proportion of total river flow passing over the spillway at the same time. Recent reviews of spill efficiency and effectiveness include Steig (1994), Giorgi (1996), Whitney et al. (1997), and Marmorek and Peters (1998). Estimates of spill efficiency vary by project.

Most spill efficiency estimates are based on hydroacoustic methodologies which make estimates for the general population, not specific species or stocks. Hydroacoustic estimates are sensitive to transducer position, fish size, and fish orientation. During the summer, hydroacoustic estimates are particularly susceptible to error caused by the presence of non-salmonids, such as juvenile shad, and high summer effectiveness values reported should be viewed with this in mind. Radiotelemetry studies have been successfully conducted at some dams, where yearling and subyearling chinook salmon and steelhead were marked, released upstream, and their behavior and route of dam passage noted. With sufficient receiving antennas and sample size, estimates of spill efficiency and effectiveness can be derived.

Steig (1994) reviewed studies at Snake and Columbia River dams conducted through 1992 and noted that there is considerable variability in daily and weekly spill effectiveness. However, he concluded that most results fall around a 1:1 relationship between the proportion of water spilled and the proportion of fish passed in spill (i.e., 1.0 spill effectiveness). Giorgi (1996) reviewed estimates of spill effectiveness published through 1993 and noted that effectiveness is poorly estimated for most species due to a combination of sparse observations, imprecise estimates, and the reliance of most estimates on hydroacoustic monitoring which is unable to distinguish among species. He cautioned that the assumption of a spill effectiveness of 1.0 could not be justified in most cases and implied that a suite of estimates acquired with different methodologies should be considered when attempting to derive species-specific estimates at individual dams. Relying largely on Giorgi's (1996) review, the PATH Hydro Work Group (PATH 1997) concluded that a range of spill effectiveness from 1.0 to 2.0 should be incorporated into sensitivity analyses of passage at Snake and Columbia River dams.

Spill efficiency at Lower Granite, Little Goose, and Lower Monumental Dams can be estimated based on radiotelemetry observations for yearling chinook salmon at Lower Granite Dam (Wilson et al. 1991), because of the similarity of the three projects. Combining the radiotelemetry observations with the assumptions that 0% of fish pass the spillway at 0% spill and 100% pass at 100% spill, the following relationship (Smith et al. 1993) can be applied:

$$P_f = 2.583P_w - 3.250P_w^{\ 2} + 1.667P_w^{\ 3}$$

where: P_f is the proportion of fish passing over the spillway (spill efficiency)
P_w is the proportion of total river flow passing over the spillway
Spill effectiveness is defined as $P_f \div P_w$.

The shape of this relationship is uncertain outside of the range of observations (20 to 40% spill), even though P_f must logically go to 0 and 1.0 at the extremes (ISG 1996).

Spill efficiency and spill effectiveness were examined in 1999 at Ice Harbor Dam using radiotelemetry (Eppard et al. 2000). The study concluded that spill efficiency was 82.6% and spill effectiveness was 1.8:1 during 2000 BiOp day conditions (approximately 45% spill). During nighttime BiOp conditions (approximately 100% spill), spill efficiency increased to 96.1%, however, spill effectiveness was closer to a 1:1 relationship. This suggests that there may be a level of spill at Ice Harbor Dam above which there is no gain in spill effectiveness at passing fish.

In 2003, radiotelemetry studies were conducted by Eppard et al. (2003) from April 29 to June 6 at Ice Harbor Dam to evaluate relative spillway passage and project survival for hatchery yearling chinook salmon under a 50% voluntary spill operation versus the 2000 BiOp spill operation. Overall spill efficiency during this study was 88.5% (95% CI, 83.7-93.2) and spill effectiveness was 1.5 (95% CI, 1.4-1.6).

Hydroacoustic evaluations of these two spill conditions were also conducted at Ice Harbor Dam from April 15 to July 15 in 2003 (Moursund et al. 2003). Spill efficiency for spring migrants was 75.9 and 51.7% for BiOp spill and 50% spill, respectively (significantly different) and spill effectiveness was 1.12 and 1.01, respectively. For summer migrants, spill efficiency was 70.8 and 64.4% for BiOp spill and 50% spill, respectively, and spill effectiveness was 10.7 and 1.27, respectively (significantly different). Moursund et al. (2003) concluded that route specific passage and project-wide performance metrics differed among operational treatments.

Passage of radio- and PIT-tagged yearling chinook salmon was evaluated at McNary Dam in 2002 by Axel et al. (in prep.a) during day and nighttime operations from 5 May to 5 June. Nighttime spill remained relatively constant throughout this period (to 120% TDG cap) but daytime spill increased considerably as of May 21 to accommodate increased river flows. Overall spill efficiency was 47% (95% CI, 27-67) and mean spill effectiveness (for Snake River migrants) was 1.12 (95% CI, 0.91-1.33).

Axel et al. (in prep.b) evaluated passage behavior for radio-tagged Columbia and Snake River yearling chinook salmon at McNary Dam in 2003. During the first 3 weeks of the study period, from late April to early June, spill was at BiOp levels (nighttime spill to 120% TDG cap), but involuntary daytime spill began on May 26 due to increased river flows. Spill efficiency was 47% for Snake River fish and 49% for Columbia River fish; mean spill effectiveness for Snake River migrants was 1.43 and for Columbia River migrants was 1.32.

At John Day Dam in 1999 a constant nighttime spill of 60% was scheduled (but observed spill was actually 45%), and daytime spill was 0 and 30%, each scheduled for 3-d continuous periods within each replicate. Johnston and Nealson (1999) measured nighttime spill efficiencies hydroacoustically during the spring at John Day Dam that were lower than reported previously, ranging from 1.4 to 1.7; however, there were potential problems with transducer placement. During the summer, 24-h spill effectiveness ranged from 2.4 to 5.1, while nighttime spill effectiveness ranged from 2.4 to 3.3. Both the spring and summer periods exhibited significantly higher 24-h spill effectiveness during the 30% daytime spill treatment.

Using radio-tagged steelhead, Hansel and Beeman (1999) found spill efficiency was not significantly different between the two treatments, at 46 and 54%, although efficiency was higher during the treatment that included daytime spill. For radio-tagged yearling chinook salmon, spill efficiency was 53 and 65%; the periods when daytime spill was provided were significantly different and greater than the treatments without daytime spill.

In spring of 2000, Beeman et al. (2001) evaluated spill passage under two day/night treatments (0/60% and 30/60%) at John Day Dam using radio-tagged steelhead and yearling chinook salmon. For chinook salmon, spill efficiency was significantly higher for 24-h spill (86%, CI 80-90) than for nighttime only spill (75%, CI 68-81). For steelhead, spill efficiency ranged from 64-83% for 24-h spill and 61-79% for nighttime only spill (no CIs reported). Spill efficiency for chinook salmon and steelhead passing through day spill was 92 and 68%, respectively. Spill efficiency for chinook salmon passing through night was 78% for both spill treatments and for steelhead, 72% during the 12-h treatment and 78% during the 24-h treatment. Also reported by Beeman et al. (2001), day spill at John Day Dam in 2000 was extremely effective for yearling chinook salmon (2.9-3.2) and for steelhead. During night spill (actual night spill ranged from 50-54%), spill effectiveness ranged between 1.4 and 1.6 for chinook salmon and 1.2 to 1.7 for steelhead.

The same two spill treatments were evaluated for passage of radio-tagged subyearling chinook salmon at John Day Dam in summer of 2000 (Beeman et al. 2002a). Spill efficiency was significantly higher for the 24-h treatment (82%) than for the 12-h treatment (54%), and spill effectiveness was greater for the 30% day spill (2.6-3.0) than for the 60% night spill (1.1-1.6).

In 2002, Moursund et al. (2003) conducted hydroacoustic studies at John Day Dam to estimate fish passage efficiency for 24-h (30%) and 12-h (0% day-60% night) spill treatments. With 12-h spill in spring, spill efficiency was 78% (±6) and spill effectiveness was 2.90 (±0.30); with the 24-h spill treatment, efficiency was 72% (±5) and effectiveness was 2.68 (±0.26). With 12-h spill in summer, spill efficiency was 58% (±11) and spill effectiveness was 2.10 (±0.30); with the 24-h spill treatment, efficiency was 61% (±12) and effectiveness 2.30 (±0.32). None of the differences for either spring or summer were statistically different.

Beeman et al. (2002a) also evaluated fish passage with 12- and 24-h spill treatments at John Day Dam in 2002 and found no significant difference in spill efficiency between treatments for radio-tagged, hatchery yearling chinook salmon. Night spill efficiency for yearling chinook salmon was significantly higher during the 12-h spill treatment than during the 24-h treatment, whereas night spill efficiency for wild steelhead was similar during the two spill treatments.

In contrast to all other dams, the powerhouse of The Dalles Dam is oriented nearly parallel to the natural course of the river, while the spillway is located on what was a shallow basalt bluff. The Independent Scientific Group (ISG 1996) suggests it is not surprising that this project exhibits higher spill efficiency than many other projects, due to its unique configuration. Giorgi and Stevenson (1995) reviewed biological investigations that described smolt passage behavior at The Dalles Dam and discussed implications to future surface bypass research. They cited three investigations that indicated that spill effectiveness was near 2.0 when about 20% of the flow passed over the spillway. These included Willis (1982), which describes a curvilinear relationship in which spill effectiveness is equal to or greater than 2.0 at spill below approximately 30% of total river flow, declining to about 1.4 at 60% spill, and further declining to 1.0 at 100% spill.

A 1996 radiotelemetry study at The Dalles Dam by Holmberg et al. (1998) supports this general relationship. Spill effectiveness for yearling chinook was 2.3 at 30% spill and 1.25 at 64% spill in 1996. PATH (1997) reviewed the available information and suggested that a factor of 2.0 be applied at The Dalles Dam at spill levels up to 30%; when spill levels are above 30% spill, the relationship grades from 2.0 to 1.0. This relationship predicts a spill effectiveness of 1.5 at 65% spill.

Hansel et al. (2000) evaluated fish passage under two spill conditions (30% and 64%) at The Dalles Dam from May 7 to May 29 of 1999 using radio-tagged yearling chinook salmon and steelhead. For 30% spill, they reported spill efficiencies of 51% (46-57) and 66% (60-71) for chinook salmon and steelhead, respectively; for 64% spill, spill efficiencies of 79% (74-84) and 86% (82-90), for chinook salmon and steelhead, respectively. Spill effectiveness for 30% spill, was 1.7 and 2.2 for chinook salmon and steelhead, respectively, and for 64% spill, 1.3 and 1.4 for chinook salmon and steelhead, respectively.

Beeman et al. (2000a, b) evaluated spill efficiency and effectiveness during spring and summer at The Dalles Dam under constant conditions of 40% spill. From April 28 to May 26, with river flows ranging from 217 to 305 kcfs, spill efficiency for radio-tagged yearling spring chinook was 86% (95% CI, 83-89) during the day and 71% (95% CI, 67-76) at night; for steelhead, spill efficiency was 88% (95% CI, 84-91) during the day and 82% (95% CI, 77-85) at night. Spill effectiveness for both yearling spring chinook and steelhead was 2.2 during the day, and 1.8 for chinook and 2.1 for steelhead at night.

For the period June 28 to July 20, under 39-40% spill (with river flows ranging from 107 to 281 kcfs) Beeman et al. (2000b) reported spill efficiency for radio-tagged fall chinook was 85% (95% CI, 78-91) during the day and 73% (95% CI, 63-82) at night at The Dalles Dam. Spill effectiveness was higher during the day than at night, 2.15 vs. 1.86, respectively.

Moursund et al. (2001c) conducted a hydroacoustic evaluation of fish passage at The Dalles Dam in spring and summer 2000. For the period May 13 to June 6, under average spill of 32% (river flows averaged 234 kcfs), spill efficiency was 89% during the day and 83% at night. For the period June 6 to July 6, under average spill of 31% (river flows averaged 192 kcfs), spill efficiency was 75% during the day and 73% at night.

Ploskey et al. (2000) conducted a hydroacoustic evaluation of fish passage at Bonneville Dam in 2000. Under average spill of 33% in spring, spill efficiency was 44% and spill effectiveness was 1.36. Under average spill of 48% in summer, spill efficiency was 49% and spill effectiveness was 1.03.

Schilt et al. (2002) conducted a hydroacoustic study to provide project-wide estimates of FPE, spill efficiency, and spill effectiveness for run-of-the-river fish passing Bonneville Dam in 2002. In spring, the spillway discharged about 44% of total river flow and spill efficiency averaged 57% and spill effectiveness was 1.17. In summer, 48% of river flow was spilled and spill efficiency averaged 42% and spill effectiveness was 0.97. For spill levels <100, 100-125, and >125 kcfs, spring spill efficiency was 41, 54, and 66%, respectively; summer spill efficiency was 22, 39, and 50%, respectively.

For spring of 2001 (unusually low river flow year) at Bonneville Dam, Evans et al. (2001b) reported spill efficiency for radio-tagged yearling chinook salmon was 30% with 37% spill and 1% with 2% spill (adult attraction spill); spill effectiveness was 0.86 and 0.53 for the two spill levels, respectively. Overall for the spring season, spill efficiency was 16% with 22% spill and spill effectiveness was 0.7. During summer, overall spill was 2.4% and spill efficiency for subyearling chinook salmon was 2%.

Evans et al. (2002) evaluated passage behavior of radio-tagged yearling chinook salmon and steelhead at Bonneville Dam in 2002. During the early May 2 to June 9 study period, 49% of the river flow was spilled. For three spill treatments (75 kcfs during day, up to 137.6 kcfs during day, and up to 141.0 kcfs during night), spill efficiency for yearling chinook was 42, 63, and 59%, respectively (57% overall); for steelhead, spill efficiency was 32, 70, and 49%, respectively (55% overall). Spill effectiveness for chinook salmon during the three treatments was 1.3, 1.2, and 1.1, respectively (1.2 overall); for steelhead, spill effectiveness was 1.0, 1.4, and 1.0, respectively (1.1 overall).

Spill Survival

Whitney et al. (1997) reviewed 13 estimates of spill mortality for salmonids (3 steelhead and 10 salmon) published through 1995 and concluded that 0 to 2% is the most likely mortality range for standard spill bays. They also pointed out that local conditions, such as back eddies or other situations that may favor the presence of predators and may lead to higher spill mortality.

Some point estimates for mortality in spill bays with flow deflectors are higher than estimates for spill bays without deflectors. For example, the highest estimates of survival for yearling chinook salmon and steelhead at Snake River dams were obtained from spill bays without flow deflectors, ranging from 0.984 to 1.000 (Muir et al. 1995b, 1996, 1998). Although lower survival estimates were obtained from spill bays with flow defectors (ranging from 0.927 to 1.000; Iwamoto et al. 1994; Muir et al. 1995b, 1998), differences in survival between the two types of spill bays compared pairwise were not significant for steelhead at Little Goose Dam or yearling chinook salmon at Lower Monumental Dam.

Eppard et al. (2003) also reported that at Ice Harbor Dam, survival was lower over spillways with flow deflectors when flows were lower during the spring of 2002 and the summers of 2000 and 2002. These authors suggested that the lower survivals may have been due to hydraulic conditions in the stilling basin when flows were less than 90 kcfs. Survival of hatchery yearling chinook salmon was 0.892 (95% CI, 0.841-0.943) in 2002. Survival of hatchery subyearling chinook salmon was 0.894 (95% CI, 0.857-0.931) and 0.885 (95% CI, 0.856-0.915) in 2002 and 2000, respectively. In addition, for yearling chinook salmon at Lower Monumental Dam in 2003, relative survival was significantly higher (0.987 vs. 0.834) when submergence of flow deflectors increased as flows increased (Hockersmith et al. in prep.). Carlson and Duncan (2003) suggested that turbulence over the spillway ogee increased with decreased flow over the spillways at Ice Harbor Dam, causing a higher probability of fish contacting spillway surface structures during lower discharge. Flow deflectors were originally designed to reduce gas supersaturation when involuntary spill was required during periods of higher flow and subsequent higher tailrace elevation. Hence, survival over spillways with flow deflectors may be reduced somewhat when spill occurs at lower flow levels.

Survival of juvenile salmonids passing through spillways at lower Snake River dams has been evaluated, at least once, at all projects (Table 1). Among the most recent studies, Plumb et al. (2004) in evaluating the performance of a removable spillway weir at Lower Granite Dam, reported a spillway relative survival estimate of 0.931 (±0.060) for yearling chinook salmon during 12-h nighttime spill to the gas cap. Hockersmith et al. (in prep.) estimated relative survival for radio-tagged, hatchery yearling chinook salmon released in spill bays 4 and 7 during daytime operations at Lower Monumental Dam from April 29 to June 6 of 2003. Relative spillway survival was 0.896 and 0.895 for spill bays 4 and 7, respectively. Spillway survival for releases after May 23 (when average total river flow doubled, average powerhouse discharge increased threefold, and average tailwater elevation increased 4 feet) was significantly higher than for earlier releases (0.987 vs. 0.834)

In 2000, NOAA Fisheries estimated relative survival for river-run hatchery yearling and subyearling chinook salmon passing through the spillway at Ice Harbor Dam (using PIT tags) was 0.978 and 0.885, respectively (Eppard et al. 2002a). The estimate for yearling chinook salmon for this particular year was similar to previous spillway survival estimates at Little Goose (1.021; Iwamoto et al. 1994) and Lower Monumental Dams (0.927 to 0.984; Muir et al. 1995). However, in 2002 at Ice Harbor Dam, analysis of PIT-tag data indicated spillway passage survival was 0.895 and 0.890 for hatchery yearling chinook salmon under day and nighttime conditions, respectively; the overall survival estimate was 0.892. During summer, spillway passage survival for hatchery subyearling chinook was 0.876 and 0.915 for fish passing under day and nighttime conditions, respectively; the overall survival estimate was 0.894.

In 2003, Eppard et al. (2003) evaluated relative spillway passage survival under 50% voluntary spill operation versus BiOp voluntary spill operation (45 kcfs spill during the day and up to 100% spill at night). Spillway survival for hatchery yearling chinook salmon was 0.928 and 0.948 for the 50% test spill and BiOp spill operations, respectively. Also in summer 2003, Absolon et al. (2003) evaluated the survival of PIT-tagged subyearling chinook salmon passing through the spillway at Ice Harbor Dam under conditions of BiOp "bulk spill" (BiOp spill using only two or three spill bays rather than all spill bays); mean survival from spill bays 2, 3, and 4 to McNary Dam was 0.96.

Heisey et al. (2003) utilized the HI-Z balloon tag-recapture technique to evaluate spillway survival in spill bay 5 at Ice Harbor Dam under various spill conditions and release depths in spring and summer of 2003. Spring survival estimates for tagged yearling chinook were greater than 0.98 for all conditions tested and within ±0.03, 90% of the time for all conditions tested. One-hour summer survival estimates for tagged subyearling chinook were 0.889 for bulk spill, shallow release, 0.923 for bulk spill, deep release, and 0.978 for dispersed spill, deep release.

Table 1. Location, species/run type, study year, fish marking method, spill bay, test conditions, and survival estimates for spillway passage at dams on the lower Snake and Columbia Rivers. Abbreviations for dams: LGR-Lower Granite; LGO-Little Goose; LMO-Lower Monumental; IHR-Ice Harbor; MCN-McNary; JDD-John Day; TDA-The Dalles BON-Bonneville.

Dam	Species/run type	Year	Method	Flow deflector	Location	Conditions	Survival	Reference
LGR	Steelhead	1996	PIT tags	no	Bay 1	3.9 kcfs	1.01	Smith et al. 1998
LGR	Yearling chinook salmon	2003	Radiotelemetry	yes	Bays 2-8	BiOp night	0.931	Plumb et al. 2004
LGO	Steelhead	1997	PIT tags	no	Bay 1	4.9-10.0 kcfs	1.004	Muir et al. 1998
LGO	Steelhead	1997	PIT tags	yes	Bay 3	4.9-10.0 kcfs	0.972	Muir et al. 1998
LGO	Yearling chinook salmon	1993	PIT tags	yes	Bay 3	3.8 kcfs	1.021	Iwamoto et al. 1994
LMO	Coho salmon	1973	Freeze brands	yes*	Bay 2	4.5 kcfs	0.97	Long & Ossiander 1974
LMO	Coho salmon	1973	Freeze brands	yes	Bay 4	4.5 kcfs	1.1	Long & Ossiander 1974
LMO	Steelhead	1974	Freeze brands	yes	Bay 7	4.5 kcfs	0.978	Long et al. 1975
LMO	Steelhead	1974	Freeze brands	no	Bay 8	4.5 kcfs	0.755	Long et al. 1975
LMO	Subyearling chinook salmon	1972	Freeze brands	yes*	Bay 2	13.1 kcfs	0.831	Long et al. 1972
LMO	Subyearling chinook salmon	1972	Freeze brands	yes*	Bay 2	2.8kcfs	0.84	Long et al. 1972
LMO	Yearling chinook salmon	1994	PIT tags	yes	Bay 7	4.4-4.8kcfs	0.927	Muir et al. 1995a
LMO	Yearling chinook salmon	1994	PIT tags	no	Bay 8	4.4-4.8 kcfs	0.984	Muir et al. 1995a
LMO	Yearling chinook salmon	2003	Radio, PIT tags	yes	Bays 4,7	2.0-11.5kcfs	0.9	Hockersmith et al. in prep.
IHR	Yearling chinook salmon	2000	PIT tags	yes	Bays 3,5,7	BiOp night	0.978	Eppard et al. 2002a
IHR	Subyearling chinook salmon	2000	PIT tags	yes	Bays 3,5,7	BiOp night	0.885	Eppard et al. 2002a
IHR	Yearling chinook salmon	2002	PIT tags	yes	All bays	BiOp	0.892	Eppard et al. 2002b
IHR	Subyearling chinook salmon	2002	PIT tags	yes	All bays	BiOp	0.894	Eppard et al. 2002b
IHR	Yearling chinook salmon	2003	Radiotelemetry	yes	All bays	BiOp	0.948	Eppard et al. 2003
IHR	Yearling chinook salmon	2003	Radiotelemetry	yes	All bays	50% spill	0.928	Eppard et al. 2003
MCN	Subyearling chinook salmon	1955	Tattoo	no	Not specified	Not specified	0.98	Schoeneman et al. 1961
MCN	Subyearling chinook salmon	1956	Tattoo	no	Not specified	Not specified	1	Schoeneman et al. 1961
MCN	Yearling chinook salmon	2002	Radiotelemetry	yes	All bays	BiOp	0.976	Axel et al. in prep. a
MCN	Yearling chinook salmon	2003	Radiotelemetry	yes	All bays	BiOp	0.928	Axel et al. in prep. b
MCN	Yearling chinook salmon	2003	Ballon-tag	yes	Bay 5	Various	>0.98	Heisey et al. 2003
JDD	Subyearling chinook salmon	1979	Freeze brands	no	Bay 16	4.3 kcfs	0.98-1.2	Raymond & Sims 1980

Table 1. Continued.

Dam	Species/run type	Year	Method	Flow deflector	Location	Conditions	Survival	Reference
JDD	Yearling chinook salmon	2000	Radiotelemetry	no	All bays	0/60% spill	0.986	Counihan et al. 2001
JDD	Yearling chinook salmon	2000	Radiotelemetry	no	All bays	30/60% spill	0.937	Counihan et al. 2001
JDD	Steelhead	2000	Radiotelemetry	no	All bays	0/60% spill	0.988	Counihan et al. 2001
JDD	Steelhead	2000	Radiotelemetry	no	All bays	30/60% spill	0.905	Counihan et al. 2001
TDA	Subyearling chinook salmon	1997	PIT tags	no	All bays	64% spill	0.92	Dawley et al. 1998
TDA	Coho salmon	1997	PIT tags	no	All bays	64% spill	0.87	Dawley et al. 1998
TDA	Subyearling chinook salmon	1998	PIT tags	no	All bays	64% spill	0.75	Dawley et al. 2000a
TDA	Subyearling chinook salmon	1998	PIT tags	no	All bays	30% spill	0.89	Dawley et al. 2000a
TDA	Coho salmon	1998	PIT tags	no	All bays	64% spill	0.89	Dawley et al. 2000a
TDA	Coho salmon	1998	PIT tags	no	All bays	30% spill	0.97	Dawley et al. 2000a
TDA	Subyearling chinook salmon	1999	PIT tags	no	All bays	64% spill	0.96	Dawley et al. 2000b
TDA	Subyearling chinook salmon	1999	PIT tags	no	All bays	30% spill	1	Dawley et al. 2000b
TDA	Coho salmon	1999	PIT tags	no	All bays	64% spill	0.93	Dawley et al. 2000b
TDA	Coho salmon	1999	PIT tags	no	All bays	30% spill	0.96	Dawley et al. 2000b
TDA	Yearling chinook salmon	2000	PIT tags	no	All bays	BiOp	0.91	Absolon et al. 2002
TDA	Yearling chinook salmon	2000	Radiotelemetry	no	All bays	BiOp	0.92	Counihan et al. 2002
TDA	Subyearling chinook salmon	2000	PIT tags	no	All bays	BiOp	0.897	Absolon et al. 2002
TDA	Subyearling chinook salmon	2000	Radiotelemetry	no	All bays	BiOp	0.826	Counihan et al. 2002
TDA	Yearling chinook salmon	2002	Balloon tags	no	Bays 4, 9,13	40% spill	98.4, 98.9, 95.6	Normandeau 2003
TDA	Subyearling chinook salmon	2002	Balloon tags	no	Bays 4,9,11	40% spill	93.6, 93.3, 92.6	Normandeau 2003
TDA	Chinook salmon	2002	Balloon tags	no	Bay 2	4.5,12 kcfs	0.949, 1.00	Normandeau 2004
TDA	Chinook salmon	2002	Balloon tags	no	Bay 4	4.5,12 kcfs	0.965, 0.995	Normandeau 2004
TDA	Chinook salmon	2003	Balloon tags	no	Bay 2	9-21 kcfs	0.931, 1.00	Normandeau 2004
TDA	Chinook salmon	2003	Balloon tags	no	Bay 4	9-21 kcfs	0.966, 0.999	Normandeau 2004
BON	Subyearling chinook salmon	1974	Freeze brands	no	Bay11	13 kcfs	0.958	Johnsen & Dawley 1974
BON	Subyearling chinook salmon	1974	Freeze brands	yes	Bay14	13 kcfs	0.868	Johnsen & Dawley 1974
BON	Subyearling chinook salmon	1989	CWT/freeze brand	yes	Bay 5	6.8 kcfs	0.9604	Ledgerwood et al. 1990
BON	Yearling chinook salmon	2002	Radiotelemetry	yes	All bays	75 kcfs/cap	0.969	Counihan et al. 2003
BON	Yearling chinook salmon	2002	Radiotelemetry	yes	All bays	24-h cap	0.98	Counihan et al. 2003

* Flow deflector included dentates.

A number of methodologies have been used to estimate spillway survival at lower Columbia River dams, including identification of test fish by fin clips, freeze brands, coded-wire tags and freeze brands, balloon tags, PIT tags, and radio tags. Most recently at McNary Dam, Axel et al. (in prep. a) using PIT- and radio-tag detections, estimated 2002 spillway passage survival for hatchery yearling chinook salmon was 0.976. In 2003, Axel et al. (in prep. b) estimated spillway passage survival for radio-tagged, hatchery yearling chinook salmon at McNary Dam was 0.928.

Estimates of spillway passage survival at John Day Dam include a study conducted in 1979 by Raymond and Sims (1980), who found that spillway mortality relative to the tailrace was not different from 0. More recently, Counihan et al. (2001) evaluated spill survival of radio-tagged yearling chinook and steelhead under two day/night spill conditions at John Day Dam in 2000. For the two spill conditions (0/60% and 30/60%), survival was 0.986 and 0.937 for yearling chinook, and 0.988 and 0.905 for steelhead, respectively.

At The Dalles Dam, Dawley et al. (1998b) released PIT-tagged subyearling chinook and coho salmon in 1997, and estimated spillway survival of 0.87 and 0.92, respectively, with 64% spill. Results from a 1998 study (Dawley et al. 1999a) show that relative survival rates during 64% spill were 0.88 for coho salmon and 0.76 for subyearling chinook salmon, while during 30% spill survival was 0.96 and 0.92 for coho and subyearling chinook salmon, respectively.

Analysis of data from 1999 show that relative survival rates during 64% spill were 0.94 for coho salmon and 0.95 for subyearling chinook salmon, while during 30% spill survival was 0.96 and 1.00 for coho and subyearling chinook salmon, respectively (Dawley et al. 2000b). In 2000, Absolon et al. (2002) estimated relative survivals at a 40% spill volume of 0.95 for yearling chinook and coho salmon and 0.92 for subyearling chinook salmon.

After 2000, spill research at The Dalles Dam shifted to causative mechanisms for the observed high mortality. Direct survival studies and studies of scale hydraulic models indicated that fish retention time in the spill basin might be the cause of the increased injury and mortality. The hydraulic model investigations had shown that flow from bay 4 moved directly out of the stilling basin while flow from more southern bays like bay 9 tended to recirculate for a period of time before moving out of the stilling basin. To evaluate the hypothesis that fish released in Bay 9 would show higher mortality, Normandeau et al. (2003) evaluated direct survival by releasing HI-Z balloon-tagged yearling chinook salmon directly into bays 4, 9, and 13 during spring 2002 (May 14-27), and subyearling chinook salmon into bays 4, 9 and 11 during summer (August 15-22).

Control fish were released below bay 3. Spring survival for bays 4, 9 and 13 was 0.984, 0.989, and 0.959, respectively. Bay 13 survival was significantly lower than the other two. For summer in bays 4, 9, and 11, survival was 0.936, 0.933, and 0.926, respectively. Eye injuries were most prevalent followed by scrapes and operculum damage. Injuries were thought to be mainly from shear and physical contact with solid objects.

In fall 2002 and spring 2003, Normandeau et al. (2004) again used HI-Z balloon-tagged chinook salmon to estimate direct passage survival through spill bays 2 and 4 under low (fall) and high (spring) tailwater conditions at The Dalles Dam. In the low tailwater test, 48-h survival rates for spill bay 2 ranged from 0.949 (deep release at 4.5 kcfs) to 1.000 (releases at 12 kcfs). Survival estimates for spill bay 4 ranged from 0.965 to 0.995, at 4.5 and 12 kcfs, respectively. Spring survival estimates for spill bay 2 ranged from 0.931 (deep/edge release at 9 and 21 kcfs) to 1.000 (deep/mid release at 18 kcfs). Spill bay 2 deep/mid release survival estimates were high (0.975-1.000) at all four volumes. Survival rates for spill bay 2 deep/off-center releases were >0.99 for the 12 and 18 kcfs releases but 0.931 for both the 9 and 21 kcfs spill volumes. Spill bay 4 survival estimates for four test conditions (all mid releases) in spring ranged from 0.966 to 0.999. The researchers concluded that safe fish passage was maximized at spill bay volumes of 12 and 18 kcfs with a total spill of 108 to 112 kcfs. Fish released at greater depth and off-center in spillbay 2 appeared to have higher rates of injury; eye damage and/or head and body bruises were generally the most prevalent visible injury types in both fall and spring.

At Bonneville Dam, Holmes (1952) estimated that subyearling chinook salmon survival through the spillway was from 0.96 to 0.97, depending on how the data were analyzed. Johnsen and Dawley (1974) compared the survival of subyearling chinook salmon passing through spill bays with and without flow deflectors, and found that relative survival was 0.868 and 0.958, respectively. Ledgerwood et al. (1990) found that survival of subyearling chinook through spill bay 5 was not significantly different than for fish released downstream. Based on the balloon-tag methodology, the calculated survival probabilities for deflector and non-deflector spillways were both 1.0 at Bonneville Dam; however, fish passing through a spill bay without a spill deflector displayed a slightly higher injury rate (Normandeau et al. 1996a).

Counihan et al. (2003) evaluated spillway passage at Bonneville Dam in 2002 with radio-tagged yearling chinook salmon. The project was operated with powerhouse 2 priority, and spill was alternated between 75 kcfs day/gas cap at night and a test condition of gas cap for 24 h; spillway survival was 0.969 and 0.980, respectively.

Causal Mechanisms Affecting Spill Survival

As pointed out in Table 1 and discussed in the spill survival section, above, many point estimates of survival through spillways made in recent years under contemporary conditions using PIT- or radio-tag methodologies are less than 0.98, a value typically used in recent model studies of survival through the hydropower system (NMFS 2000; Marmorek et al. 1998). In general, these lower survival estimates apply to Lower Monumental, Ice Harbor, Lower Granite, and The Dalles Dams, and suggest that conditions juvenile salmonids experience during spillway passage may differ among dams and within a dam spillway under various conditions. Here we summarize information developed to date on spillway passage survival at these dams.

Ruggles and Murray (1983) reviewed fish responses to passage through spillways at Canadian dams and concluded that spillways were not a serious source of fish mortality. They pointed out that fish may be injured by rapid pressure change, rapid deceleration, shear forces, turbulence, abrasion, and the force of striking water in free fall. They noted that spillway deflectors have been used successfully to reduce air entrainment associated with deep plunging jets, and that injuries begin to occur when the impact velocity of a fish striking the water surface exceeds 53 fts^{-1}. Based on a need to design spillway flow deflectors for gas abatement, the Corps initiated a literature review of physical injury through spillways through their Dissolved Gas Abatement Study. The study considered three injury types: immediate mechanical injury, short-term delayed injury, and longer-term delayed injury. It concluded that results from studies of impacts from gas abatement structures (such as flow deflectors) have been inconsistent, and effects from gas abatement structures could not be separated from effects associated with passage through the total spillway environment. Immediate direct mortality was the injury type most studied and best understood, and long-term delayed mortality was the least studied and understood. The report noted that gas abatement structures can produce hazardous conditions, such as shear zones (R2 Resources 1997).

Several years of research conducted at The Dalles Dam was summarized by Ploskey et al. (2001). A spill discharge of 40% of total project discharge was adopted as the best operation and implemented in the spring of 2000. However, testing that year showed that survival was still low in 6 of 8 conditions tested, which included 2 spillway release locations (north and south), and daytime and nighttime releases during both the spring and summer periods. Average survival ranged from 0.842 for summer, daytime, north spillway to 1.026 for spring, daytime, north spillway (Absolon et al. 2002). Subsequently, a committee of engineers and biologists used a 1:80 scale general hydraulic model at the Corps Engineering Research and Development Center in Vicksburg, MS to evaluate physical conditions associated with these elevated spillway mortality rates. They concluded that large volumes of spill through the northern half of the spillway, designed to enhance tailrace egress, resulted in flow from southern spill bays moving northward within the stilling basin. This increased retention time in the basin, along with it being half the depth of the next shallowest basin of the FCRPS dams, suggested that mechanical injury from strike and shear in the turbulent stilling basin was causing the reduced survival.

Results from more recent radiotelemetry (Beeman et al. 2002; 2003) and balloon-tag (Normandeau, 2003b) studies corroborate these observations. Therefore, an extension of the pier wall between bays 6 and 7 downstream to the stilling basin end-sill was evaluated in the Corps hydraulic model. In the model, the wall reduced retention time in the stilling basin when six, northern-most spill bays were operated under uniform discharges of from 8 to 20 kcfs. The pier wall extension was installed at The Dalles Dam prior to 2004. Preliminary results based on balloon tagging indicate direct survival was greater than 0.98, and more than 96.8% of the test fish showed no signs of injury (Mike Langeslay, Corps of Engineers, personal communication, May 2004).

At Ice Harbor Dam, spillway survival of radio-tagged yearling chinook salmon averaged 0.978 in 2000, and 0.892 in 2002 (Eppard et al. 2001, 2003). The 2000 Biological Opinion called for night spill up to 100 kcfs (the gas cap limit) and day spill of 45 kcfs during the spring at Ice Harbor Dam, with uniform spill discharge across bays. To further investigate survival associated with higher (plunging flow) and lower (skimming flow) spill volumes, BiOp and 50% spills were tested during the spring of 2003 using a 2-day block study design. Relative spillway passage survivals were similar, with 0.948 (95% CI, 0.915-0.981) for the BiOp spill and 0.928 (95% CI, 0.860-1.000) for the 50% spill. Also that year, estimated survival of balloon-tagged yearling chinook salmon released at two locations (elevations) in spill bay 5 was greater than 0.98 during all conditions tested (Heisey et al. 2003). Although fish injuries ranged as high as 22% for releases made at the deepest elevation and were 8% or less for the shallower release location (Heisey et al. 2003), these release locations appeared to represent a relatively low percentage of the overall population passing the spill bay (Moursand et al. (2003b). Efforts to resolve this issue are continuing. In 2004, preliminary results from balloon-tag studies with yearling migrants released at locations more representative of the overall population indicate survival was still high (>0.98), but injury rates were reduced to 2% (Marvin Shutters, Corps of Engineers, personal communication, May 2004).

Survival of subyearling chinook salmon at Ice Harbor Dam during the summer averaged 0.885 in 2000 and 0.894 in 2002 (Eppard et al. 2001, 2003). In 2003, a bulk-spill pattern was developed where more than 10 kcfs was spilled through fewer bays, as compared to the pattern of uniform spill through all bays. Estimated survival of

PIT-tagged subyearling chinook salmon was 0.96 (95% CI, 0.90-1.10; Absolon et al. 2003). When compared to 2000 and 2002, these results suggest the bulk-spill pattern may reduce fish exposures to physical conditions that cause injuries. In contrast, 1-h estimated survival under the bulk spill pattern based on balloon-tagged, river-run subyearling chinook salmon, was 0.89 and 0.92 for shallow and deep spill bay release locations, compared to an estimated 1-h survival of 0.98 for fish released through a deep release under the uniform spill pattern (Heisey et al. 2003). However, the authors indicated there were problems related to high temperatures during this test, suggesting a need for caution when interpreting these data.

At Lower Monumental Dam, Muir et al. (2001a) found that survival of PIT-tagged yearling migrants was lower though spill bays with deflectors, compared to standard bays. The study did not address differences between spill bay locations, discharges, or tailwater elevations. Prior to 2003, additional deflectors were installed in the end-bays of the spillway, and with these in place, from 25 to 40 kcfs could be spilled while maintaining gas criteria at downstream locations under 24-h spill. In 2003, Hockersmith et al. (in prep.) evaluated spillway survival based on radio-tagged yearling chinook salmon where spill was distributed uniformly between spill bays. Relative survival through the spillway was 0.900 (95% CI, 0.843-0.961). Relative survival through spill bays 4 and 7 was similar, at 0.896 (95% CI, 0.779-1.031) and 0.895 (95% CI, 0.724-1.106), respectively. However, spill discharge early in the season was in the gas cap range noted above when total river discharge was less than 75 kcfs, but was outside this range later in the season when total river discharge increased. Additional analysis of the data suggested there was a tailwater elevation effect, where survival was low when tailwater elevation was low (0.834 (95% CI, 0.78-0.90), 440 ft msl, 76 kcfs river flow), and high when tailwater elevation was high (0.987, 95% CI, 0.92-1.06; 444 ft msl, 150 kcfs river flow).

In summary, fish survival through spillways at these dams is influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spill bay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and thus total river flow, gate opening, and fish location when passing through the spill bay and under the control gate. Efforts to further explore the relationships between these factors are ongoing. Hydraulic model studies indicate that deflector submergence (tailwater elevation) directly influences the hydraulic behavior of the spill jet as it passes over the deflector. Under conditions of high discharge and low submergence of the deflector, the jet passes over the deflector and plunges abruptly into the stilling basin. This operation was tested during the summer of 2003 at Ice Harbor Dam and resulted in an estimated average survival of 0.96. Under conditions of moderate discharge and higher deflector submergence, the spill bay discharge jet is deflected upward, creating an undular, ramped, or submerged hydraulic jump. This operation was tested during the spring of 2003 and resulted in an estimated average survival of 0.99 at Lower Monumental Dam. Under both conditions, the spillway discharge jet appears to dissipate relatively quickly and produces low impacts on juvenile salmonids passing through the discharge, even though jet velocities are high (>60 ft s^{-1}). Conversely, under conditions of low discharge per spill bay, certain tailwater elevations, and uniform spill between bays, the discharge jet performs as designed and skims off the deflector and stays near the tailrace water surface for an extended distance downstream. This operation was tested during the spring of 2002 and resulted in an estimated average survival of 0.89 at Ice Harbor Dam, and 0.83 during the spring of 2003 at Lower Monumental Dam.

Based on this information, a possible explanation of the low survival associated with skimming flow off the deflector is that a shear zone is created on the underside of the jet and fish in the lower portion of the nappe are exposed to this zone which results in injuries. The zone of injury occurs until a point downstream where jet velocity drops to below 50 fts^{-1}, a threshold considered safe based on field and laboratory studies (Ruggles and Murray 1983, Pacific Northwest National Laboratory et al. 2001). If this explanation is the case, lowering the elevation of the deflector to produce hydraulic jump conditions a greater percentage of the time, or changing to higher discharges through fewer spill bays ("bulk" spill) may reduce injury and mortality rates. Clearly, additional field and hydraulic model studies will be needed to verify this explanation, understand the implications for gas abatement, and design solutions to these conditions.

The observations of spillway survival at The Dalles, Ice Harbor, and Lower Monumental Dams suggest that survival of juvenile salmonids through spillways is influenced by many physical factors. Lessons learned from these studies should be applied to others spillways that have deflectors, and training spill associated with the Removable Spillway Weir at Lower Granite Dam and others weirs that may be installed in the future.

Forebay Passage and Predation

Beamesderfer and Rieman (1991) found that forebay populations of northern pikeminnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieui*) were present in substantial numbers in the forebay of John Day Dam. Poe et al. (1991) reported that the diet of northern pikeminnow in the forebay of John Day Dam was 66% salmonid smolts. In addition, detection histories for radio-tags (from hatchery yearling chinook salmon) recovered from the Crescent Island Caspian Tern colony near the mouth of the Snake River indicated that, at a minimum, terns from this colony forage from Ice Harbor Dam forebay to McNary Dam forebay (Axel et al. 2003). This suggests that delay of juvenile migrants in forebays could reduce survival due to increased predation, and project operations such as daytime spill that decrease forebay residence time could increase survival.

Axel et al. (2003) evaluated passage behavior at Ice Harbor Dam in 2001 under low flow (69.5 kcfs), no spill conditions and reported a median forebay residence time for radio-tagged hatchery yearling chinook salmon of 7.3 h. Schools of yearling chinook salmon were observed holding within the immediate forebay of Ice Harbor Dam on a daily basis throughout the study period (May 8-28). A previous radiotelemetry study conducted at Ice Harbor Dam in 1999 by Eppard et al. (2000) reported that median forebay residence time for radio-tagged hatchery yearling chinook salmon was 1.3 h, with average river flows of 109.7 kcfs and spill averaging 45% (54 kcfs) during the day and 81% (94.2 kcfs) at night.

Radiotelemetry data reported by Axel et al. (2003) regarding passage of radio-tagged hatchery yearling chinook salmon at McNary Dam in 2001 also indicated prolonged residence time within the forebay under low flow, no spill conditions (7.6 h). Detection histories indicated that once fish entered the forebay, they constantly moved back and forth across the spillway and powerhouse before passing.

At Lower Granite Dam in 2003, median forebay passage times during R.W. tests were 1.92, 1.72, and 2.28 h for radio-tagged hatchery and wild steelhead, and hatchery chinook salmon, respectively. For these same test groups, median passage times during spill-to-the-gas-cap tests were 7.37, 4.64, and 4.98 h, respectively (Plumb et al. 2003).

Tailrace Passage and Predation

The concept of developing spill patterns at FCRPS dams specifically for fish passage was first addressed systematically in the 1960s to facilitate adult salmon passage into the adult fish collection systems. June (1967) observed improved adult salmonid passage under intermediate to large spill volumes if four or five gates at each end of the spillway were at low volume settings. At large dams this resulted in a tapered spill pattern near each end and a flat spill pattern across the central portion of the spillway. At smaller dams this produced a “crowned” pattern across the entire spillway tailrace, with the highest discharge in the middle bays.

June evaluated adult salmon passage success by comparing ladder passage counts associated with various spill patterns. The spill pattens he developed that appeared best for adult passage conflict with what is thought today to be best for juvenile passage (high shoreline velocities), since June kept near-shore velocities low to facilitate adult migration and passage into fishway entrances located along shorelines.

Smolt residence time in spillway tailraces is likely influenced by spill volume and pattern. High spill volume and water velocity push water and presumably juvenile salmonids out of the immediate tailrace, and help redistribute piscivorous predators (northern pikeminnow) away from the immediate spillway tailrace, reducing potential predation opportunities (Faler et al. 1988). Shively et al. (1996) found that ambient river flow velocities of at least 1 m s^{-1} were necessary to keep northern pikeminnow from holding in areas near bypass outfalls, and that the degree by which water velocity eliminated northern pikeminnow holding increased as outfall distance from shore and water depth increased.

Hansel et al. (1993) found that hydraulic cover such as eddies and backwaters at velocities below this threshold were preferred northern pikeminnow feeding habitats, particularly when near primary smolt migration paths. Spill patterns that facilitate rapid juvenile egress from the spillway stilling basin through the tailrace likely increase juvenile survival. Current spill patterns are developed to increase the survival of juvenile fish through tailraces, by emphasizing minimizing hydraulic cover and maintaining high water velocities near spillway shorelines. To not interfere with daytime adult passage, these juvenile spill patterns are often employed during nighttime hours only (COE 2004).

As information is gained on the use and benefits associated with daytime spill to pass juveniles, greater consideration will likely be given to the use of juvenile spill patterns during the daytime. Spill patterns that attempt to satisfy both adult and juvenile passage criteria during the daytime have been developed for Lower Granite, Ice Harbor, McNary, John Day, The Dalles, and Bonneville Dams using scale hydraulic physical models at the COE Engineering Research and Development Center (ERDC) in Vicksburg, MS. Patterns for each dam for day and nighttime periods are developed in coordination with salmon managers and incorporated into the Annual Fish Passage Plan (COE 2004).

Eppard et al. (2000) evaluated tailrace residence times of radio-tagged, yearling spring chinook at Ice Harbor Dam during spring 1999. Spill levels during the study were as high as 45% of total river flow during the day and up to 100% at night. Median tailrace residence times were 2.7 , 5.7, and 7.3 min for fish that passed through the spillway, juvenile bypass system, and turbines, respectively, during daylight hours. At night during 100% spill, median tailrace residence time was 3 min for spillway passed fish. During spring 2001 at Ice Harbor Dam (low flow, no spill), median tailrace residence times were 9.0 and 14.7 min for radio-tagged, yearling spring chinook that passed the through the bypass system and a turbine unit, respectively.

At McNary Dam in spring 2002, radiotelemetry analysis of yearling chinook salmon passage identified a statistically significant difference between median tailrace egress times for spilled fish (5.5 min) and bypassed fish (10.2 min; Axel et al. in prep. a). While there was also a significant difference in tailrace egress times between fish bypassed during the day (9.4 min) and night (11.4 min), there was no day/night difference observed for fish passing through spill. Within the spillway, slightly longer tailrace egress times were observed for fish passing through the end bays.

At McNary Dam in spring 2003, Axel et al. (in prep. b) also observed a significant difference between median tailrace egress times for radio-tagged yearling chinook salmon passing through the spillway (5.8 min) and the bypass system (7.7 min). No diel differences in egress times were observed for spilled fish, but as in 2002, longer egress times were associated with fish passing through the end spill bays.

At John Day Dam, Liedtke et al. (1999) observed good juvenile egress through the spillway tailrace with a new spill pattern; marked yearling and subyearling fish passed through the first 0.7 km of tailrace in 5 to 10 min. They also observed slower passage times and higher predation rates on fish that passed through end spill bays.

In 2000, Duran et al. (2002) monitored tailrace egress at John Day Dam and concluded spillway passage generally resulted in more rapid tailrace egress than bypass passage. Residence times for spilled fish were similar for radio-tagged fish released at day 30% spill and night 60% spill. Residence times were longer for bypassed fish during the 60% night than 30% day spill. Spill passed yearling chinook exited the tailrace within about 10 min for all spill conditions and bypassed yearling chinook took 6 min longer to exit tailrace (15 vs. 9 min) under the night 60% spill treatment. Spill passed steelhead tailrace exit times and relationships were similar, although the test was compromised by lower than requested spill percentages. South spillway passed fish took longer than north (12-14 vs. 7-8 min). For subyearling chinook salmon, residence times for spill passed fish were generally lower during 60% night spill than for 30% day spill. North spillway fish had the lowest residence times. Subyearlings released at the bypass had significantly longer tailrace egress times during 60% night spill than during 30% day spill (74 vs. 17 min).

At The Dalles Dam in 2000, Allen et al. (2001) reported that radio-tagged yearling and subyearling chinook salmon that passed through the powerhouse in spring and summer had double the tailrace residence times of north spillway passed or control fish. Sluiceway and south spillway fish tailrace residence times were similar to powerhouse times.

Daily Spill Timing

The early spill programs based daily spill timing on hourly monitoring of smolt abundance at projects where this information was available. If hourly information was not available, daily spill timing was determined prior to each season and was based on the best available diel passage information. This diel information was obtained from smolt monitoring or research activities conducted primarily at powerhouses, rather than spillways, and it was common to apply diel information collected at one dam to another. However, more recent studies have shown that diel passage timing through spillways is different than powerhouses. For example, while smolt monitoring information suggests 60 to 90% of the daily powerhouse passage at John Day and Lower Monumental Dams occurs from 1800 to 0600 (Ransom and McFadden 1987, Martinson et al. 1997), hydroacoustic studies indicate that both day and night passage of juvenile migrants through the spillway is high at both dams during involuntary daytime spill (Johnson et al. 1998, BioSonics Inc. 1999a, b).

Observations at The Dalles and Bonneville Dams also indicate that spillway passage occurs at fairly constant rates, day and night, if daytime spill is provided (BioSonics Inc. 1997, Hensleigh et al. 1998). This suggests that juvenile migrations may be delayed if spill is managed based on powerhouse diel passage patterns. Studies conducted at John Day Dam in years with little daytime spill found that fish often milled in front of the dam when they arrived during the day and passed the dam at night, most often through the powerhouse (Giorgi et al. 1985, Sheer et al. 1997). Sheer et al. (1997) found that fish passing The Dalles Dam during 24-h spill delayed very little, and most (85%) passed through the spillway. Hensleigh et al. (1999) and Liedtke et al. (1999) found a similar response at John Day Dam, where radio-tagged yearling and subyearling chinook salmon and steelhead had relatively short forebay residence times and high (50 to 75%) spillway passage rates during years where high flows caused high levels of daytime spill.

In radiotelemetry studies conducted in spring and summer of 1999 at John Day Dam during two, day/night spill treatments (0/60% and 30/60%), Hansel et al. (2000a, b) reported forebay residence time was significantly shorter for yearling chinook salmon passing during the day spill treatment (0.8 vs. 8.5 h), and a similar result was observed for smaller (<200 mm) steelhead. With subyearling chinook, there appeared to a greater delay for fish arriving during the day with spill that at night with spill (2.5 vs. 0.6 h) during similar spill levels, suggesting a day vs. night effect that is independent of percent spill. Also, during the 12-h spill treatment, 55% of the fish arriving during the day delayed to pass at night.

For similar day/night spill treatments (0/60% and 30/60%) at John Day Dam in 2000, Beeman et al. (2001) reported that median forebay residence time was longer for radio-tagged yearling chinook and steelhead when no day spill was provided, but this was only statistically significant for chinook (4.6-12.3 h without day spill, 1.4-3.2 h with day spill). The researchers concluded that the use of 24-h spill decreases forebay residence times of fish arriving during the day, increases spill efficiency of yearling chinook, but does not significantly alter fish passage efficiency from values obtained during 12-h spill. For radio-tagged subyearling chinook, Beeman et al. (2002a) reported fish arriving at John Day Dam during the 24-h treatment had shorter forebay residence times with less variability between day and night arrival periods than those arriving during the 12-h treatment. Median residence time during the 24-h spill for day arrival was 1 h (range 0.7-1.6 h) and for night arrival was 1.6 h (1.2-2.6 h). Median times for the 12-h spill for day arrival was 4.8 h (2.4-6.6 h) and ranged from 0.8 to 4.2 h for night arriving fish. Project fish passage efficiency was significantly higher for the 24-h spill treatment (91%) than for the 12-h treatment (79%).

For two day/night spill treatments (0/54% and 30/30%) at John Day Dam during spring 2002, Beeman et al. (2002b) reported that although median forebay residence times for radio-tagged salmonids tended to decrease with increased percent spill levels, median residence times for the 12- and 24-h treatments overall were similar for yearling spring chinook (1.7 vs. 1.6 h) and wild juvenile steelhead (6.8 vs. 7.0 h).

Seasonal Spill Timing

Historically, seasonal spill timing has been based on juvenile fish abundance. Early spill programs relied primarily on preseason planning dates and in-season estimates of cumulative fish passage as a trigger for the beginning and end of the spill season at each project. These programs were managed to provide spill for the middle 80% of the juvenile migration. These percentages were applied separately to the spring and summer migration periods and were based on actual fish sampling at each project via the smolt monitoring program (FPC 1995).

The NOAA Fisheries 2000 BiOp proposed that the actual dates of spill be determined annually by the regional Technical Management Team and based on the best available monitoring and evaluation data concerning project passage, spill, and system survival research. The 2000 BiOp established Snake River spill planning dates as April 3 to June 20 and June 21 to August 31, and lower Columbia River dates as April 10 to June 30 and July 1 to August 31.

Summer Spill

(To be developed)

Dissolved Gas/Gas Bubble Disease

Dissolved Gas Standards–Recommended total dissolved gas standards for surface waterways were developed by the U.S. Environmental Protection Agency under the authority of the 1977 Clean Water Act amendment to the Federal Water Pollution Control Act of 1948. These standards were subsequently adopted by state environmental quality agencies. Each Pacific Northwest state has slightly different statutes.

However, in the case of the mainstem Snake and Columbia Rivers, a common standard of 110% total dissolved gas supersaturation (TDGS) was adopted. Each state has provisions for a short-term waiver of the standard. In 1994, NOAA Fisheries first applied for and was granted total dissolved gas waivers from Washington and Oregon. These waivers allowed total dissolved gas levels up to 115% in the forebay and 120% in the tailrace of each FCRPS dam. The 1995 FCRPS BiOp included these standard waivers in the spill program requirements. Since 1994, NOAA Fisheries has requested and received annual water quality waivers from each state.

In 1997, the state of Washington replaced the dissolved gas standard annual waiver with a "fish passage exemption" in the Water Quality Standards for Surface Waters of the State of Washington (Chapter 173-201A-060 (4)(b)), which mandates allowable dissolved gas limits identical to those in the NOAA Fisheries BiOp, with the addition of a 1-h maximum of 125%. This exemption specifically states that it is intended for "spillage for fish passage" and is "temporary." In qualifying for this exemption, NOAA Fisheries has met annual reporting and monitoring requirements.

Table 2 presents the estimated spill volumes which result in approximately 120% TDGS at tailwater gas monitors or 115% TDGS at forebay monitors. Spill volumes vary with forebay TDGS, powerhouse flow volumes, and spillway tailwater elevations.

Dissolved Gas Supersaturation–Soon after Bonneville Dam was completed in 1938, dead adult salmon were observed downstream by fishermen (Merrell et al. 1971). Unreconciled losses of adult salmon continued through the 1950s. Westgard (1964) first documented gas bubble disease (GBD) on the Columbia River in the McNary Dam spawning channel. Dissolved gas supersaturation was documented and unequivocally associated with spill at mainstem Columbia River dams in the late 1960s by Ebel (1969). By inference, Merrell et al. (1971) attributed earlier observed adult salmon losses to supersaturation. In 1967, run-of-the-river adult and juvenile salmon were observed with GBD and holding tests linked high dissolved gas and increases in temperature with mortality of juveniles (Ebel 1969).

Adult salmon mortality was documented in conjunction with high levels of supersaturation (125 to 135%) from Wells to Chief Joseph Dams from 1965 through 1969 (Meekin and Allen 1974). In 1968, when John Day Dam was completed but before turbines were in operation, dead adult chinook and sockeye salmon were found floating downstream and live fish with signs of GBD were captured (Beiningen and Ebel 1970). From 1968 to 1975, GBD in high-flow years contributed to high mortalities of juvenile salmonids migrating from the Snake River (Ebel et al. 1975).

Many studies on GBD and its effects on salmonids were conducted in an attempt to define the threat in the mainstem Columbia and Snake Rivers. The severity of GBD was dependent upon species, life stage, body size, level of total dissolved gas, duration of exposure, water temperature, general physical condition of the fish, and swimming depth (Ebel et al. 1975). A thorough review of the literature on dissolved gas supersaturation and of recorded cases of GBD was compiled by Weitkamp and Katz (1980) and updated by Fidler and Miller (1993). Despite numerous studies, there were still questions regarding the TDGS that migrating salmonids can safely tolerate and how to evaluate impacts. In 1994, NOAA Fisheries and BPA convened a panel of experts to review dissolved gas conditions on the river and assess impacts to salmonids from GBD resulting from voluntary spill (GBD Panel 1996). The panel concluded that not enough was known to accept the hypothesis that aquatic organisms in the Columbia and Snake Rivers were not impacted by dissolved gas from voluntary spill. This conclusion initiated regional research and monitoring efforts to increase the knowledge base needed for spill management decisions. These efforts were administered by the Gas Bubble Disease Technical Work Group (now called the Water Quality Team) and was originally chaired jointly by NMFS

Table 2. Estimated spill caps.

Project	120% TDG limit (kcfs)[a]	Practical TDG spill limit (kcfs)[b]
Lower Granite	45-50	45-50
Little Goose	60	40[c]
Lower Monumental	25-40	35
Ice Harbor	95-105	95-105
McNary	160-185	160-185[d]
John Day	85-160	150-160[e]
The Dalles	95-200	150
Bonneville	145-150[f]	120-150[g]

a Spill cap based on observed gas levels at the tailwater monitor in 2002 and 2003.

b Spill cap based on observed spill flows limited by the tailwater monitor or the next forebay monitor in 2002 and 2003.

c Because of entrainment of powerhouse flow into the spillway the Little Goose spill levels are normally constrained by TDG levels in the forebay of Lower Monumental Dam.

d The McNary spill limit is an estimate since a new spill pattern will be implemented in 2004.

e The John Day limit depends on how the spill schedule is implemented as total river discharge increases. The spill pattern changes from concentrated to flat at about 108 kcfs spill. TDG levels actually decrease above this point then increase with increasing spill. We are assuming the operators will avoid the 108 kcfs limitation.

f The Bonneville spill limit is based on the new spillway tailrace monitor.

g The TDG spill limit at Bonneville is dependant on the monitor site used for management. The tailwater site provides consistent TDG results; however, the Camas site is highly variable due to local environmental conditions and may at times further limit spill levels at Bonneville Dam.

and the Environmental Protection Agency. A comprehensive review of total dissolved gas (TDG) levels and risk assessment associated with spill and can be found in Appendix E of the NMFS 2000 FCRPS BiOp.

***GBD Monitoring and Research*–**Beginning in 1994, the annual TDGS waivers from the states were granted with the stipulations that proper monitoring would be conducted and results of research and monitoring would demonstrate minimal effects from GBD at temporarily increased levels of 115% in reservoirs and 120% in tailraces at dams. A formal plan was developed by NOAA Fisheries to monitor TDGS and signs of GBD in the aquatic biota (NMFS 1997). Critical uncertainties of the monitoring program were identified (Biological Monitoring Inspection Team 1995), gas bubble disease research priorities were developed (NMFS 1996), and thresholds of 15% prevalence and 5% severe GBD signs were set for continued voluntary spill.

Through the 1990s, TDGS monitoring improved. By 1998, timely data distribution by COE included hourly dissolved gas levels and water temperatures from 41 monitoring sites in forebays and tailraces on the mainstem Columbia and Snake Rivers (COE 1998b). Quality assurance and control measures and improved gas measurement technology increased data precision and provided confidence that fisheries management decisions regarding the threat from TDGS were based on sound data. However, concerns still existed over whether the monitoring sites appropriately represent all conditions experienced by salmonids (ISAB 1999). Additionally, intensive monitoring throughout reservoirs and in tailraces has allowed a series of models to be developed that relate tailwater TDGS to spill, total project release, and forebay TDG for all mainstem dams from Grand Coulee and Lower Granite to Bonneville Dams, as well as from Dworshak Dam (COE 1998a).

Through the 1990s, GBD monitoring of migrating juvenile and adult salmonids was also greatly improved. Numbers of fish, methods, locations, and times for sampling were adjusted to provide a representative network of samples. Quality assurance and control methods met regional requirements, thus providing confidence that fisheries management decisions were based on the best possible data given the present state of technology.

Uncertainties associated with the GBD monitoring are

1) whether the relationship between smolt/adult mortality and gas bubbles in fins, gills, and lateral line is known,

2) whether clinical signs change during collection and examination,

3) whether signs in sampled fish represent the river site over the entire 24-h period,

4) whether samples are taken at representative locations, including those of high risk from GBD,

5) whether sample size is statistically adequate for required confidence limits,

6) whether key signs of GBD and their relative significance are known, and

7) whether the 15% threshold level for GBD prevalence can be tolerated by the juvenile migrant population.

Research conducted to address these uncertainties suggests:

1. The relationship between prevalence and severity of GBD signs and mortality of juvenile salmonids is unresolved. Research has produced an equivocal relationship except at consistent 130% TDGS (Mesa et al. 2000, Backman and Evans 2002).

2. Varying pressures encountered by juvenile salmonids during passage through the collection and bypass systems at dams appears to not substantially alter existing GBD signs nor induce new signs (Absolon et al. 1999). Collection protocols require fish be collected at the dewatering screens in the bypass conduit, held in river water at ambient temperature, and processed within 15 min of sampling (Maule et al. 1997). Prevalence of GBD signs in fish collected from bypass systems was somewhat greater than that of fish collected by seines from reservoirs (Backman et al. 1998). The increased GBD signs may be caused by passage delays in front of dams prior to bypass system entry. The ISAB (1999) called for more research to evaluate this difference.

3. Fish samples collected for GBD assessment of smolt monitoring facilities at Snake and Columbia River dams adequately represented fish passing through the smolt bypass systems 24 h per day (NMFS 1999b).

4. Smolt monitoring sites appeared to provide samples that were generally representative of upstream and downstream locations.

5. Evaluation of sample statistics by Maule et al. (1997) showed that numbers of sampled fish were generally sufficient to document a species-specific GBD prevalence when impacted migrants reached the NOAA Fisheries threshold of 15% prevalence or 5% severe signs of GBD. An exception is at McNary Dam where migrants from the Snake River cannot be differentiated from Columbia River migrants. Here, a low prevalence in the total sample could be associated with a large prevalence within the Snake River subpopulation. However, at dissolved gas levels present during voluntary spill, this problem is insignificant.

6. The GBD signs utilized as a GBD index for smolt monitoring are externally visible subcutaneous emphysema. Research to identify other indicators of GBD such as blood chemistry changes was not pursued. Acoustic assessment of internal gas emboli was determined too expensive and not suitable for use in field locations (Carlson 1995). Excision of gill lamella was investigated, but thought to be no better an index of GBD impacts than other less invasive methods.

7. Signs of GBD can only be utilized as a subjective tool. The GBD Panel (1996) stated that when GBD signs are observed in any fish, there should be regional concern about survival. Also, the greater the prevalence and severity of GBD signs the more concerned managers should be about fish survival.

GBD Impacts–Results of GBD monitoring and research on juvenile salmonids in the 1990s show that incidents of high prevalence and severity of GBD signs and probable related mortality are associated with exceptionally high river flows and/or exceptional dam operation problems where powerhouse flows were limited. In 1990, a fire at John Day Dam caused 100% spill for an extended period, resulting in downstream TDGS levels greater than 130% and GBD prevalence up to 74% in steelhead and 38% in coho salmon.

In 1993, turbine outages at Lower Granite Dam caused TDGS to increase resulting in 18% prevalence of GBD in migrants at Little Goose Dam. In 1995 and 1996, turbine outages at Ice Harbor Dam coupled with high river flows caused TDGS to exceed 130% during the spring freshet. PIT-tag interrogation data collected at Snake and Columbia River dams suggested losses of juvenile chinook salmon coincident with the high levels of TDGS in the 67-km reach from Lower Monumental Dam to the Snake River mouth in 1995 (Cramer 1996a) and 1996 (Cramer 1996b, NMFS 1997). However, no losses of steelhead were measured in that same river reach for fish that prior to release at Little Goose Dam had been experimentally exposed to supersaturation sufficient to produce low-grade mortality (Monk et al. 1997a). Resident fish downstream from Ice

Harbor Dam also showed high prevalence and severity of GBD signs in 1995 and 1996 (Schrank et al. 1997, 1998).

High river flows in 1996 and 1997 caused excessive spill at all mainstem dams, and TDGS exceeded 120% (the maximum allowed for voluntary spill) for extended periods throughout most of the lower Snake River and mid- and lower-Columbia River. Results of GBD monitoring showed that prevalence of subcutaneous emphysema in juvenile salmonids was minor when TDGS was 120 to 125%, but was generally 10% or greater when TDGS was higher than 125% (NMFS 1998a). Under high river flow conditions, even when all possible system management actions are taken, TDG often cannot be kept below 120%.

In the early 1990s, river flow was low and often within powerhouse hydraulic capacities. When there was sufficient market for power, voluntary spill for fish passage and TDGS at 120% in tailraces and 115% in forebays could be regulated. Effects of GBD under these conditions appeared benign, signs were minimal or non-existent, and there was no apparent GBD related mortality (Maule et al. 1997, ISAB 1999). Even during periods of involuntary spill, GBD impacts appeared to be minor, except when TDGS was over 120% (NMFS 1997, 1998a, 1999b; Backman and Evans 2002).

Impacts of GBD as measured by visual external signs in river migrants are greater at higher temperatures, particularly when the ambient water temperature of supersaturated water increases (Ebel 1969, Ebel et al. 1971). Steelhead have a lower tolerance to TDGS than other species based on Smolt Monitoring Program data (NMFS 1997, 1998a, and 1999b) and laboratory tests (Fidler and Miller 1993).

Depth Compensation–Gas solubility increases with increasing pressure. For each meter of depth there is a 10% reduction in the TDG saturation level relative to the surface saturation (Weitkamp and Katz 1980). Dawley et al. (1975) and Weitkamp (1976) reported data suggesting depth compensation occurs with juvenile salmonids as gas solubility calculations would predict. Maule et al. (1997) observed that salmonids may migrate at protective depths and presented results suggesting that the depth of tagged fish would compensate for a surface TDG level of up to approximately 124%.

Employing depth-sensitive radio tags, Beeman et al. (1998, 1999) tracked juvenile salmonids between Ice Harbor and McNary Dams at depths of 1.8 to 2.5 m with a surface TDG level of 120%, and concluded the median depth of juveniles in the McNary pool was sufficient to protect fish from TDG levels of between 117 and 124%. The authors stated that a voluntary spill program with gas caps of 115% in forebays and 120% in tailraces can be expected to prevent gas bubble disease in juvenile chinook and pose little threat to the more sensitive steelhead.

Dissolved Gas Abatement–Starting in 1994, a COE Dissolved Gas Abatement Study developed concepts for decreasing TDGS at the eight Snake and Columbia River dams. The COE is pursuing numerous potential structural modifications to spillways and stilling basins for dissolved gas abatement alternatives. While some of these alternatives may be implemented in the future, only flow deflectors have been implemented to date to reduce gas production at the FCRPS projects.

None of the gas reduction alternatives evaluated met biological, operational, and economic criteria, nor did they decrease gas levels to the 110% water quality standard for the 7-day 10-year discharge events. Whitney et al. (1997) found that under appropriate operating conditions, flow deflectors generally lowered dissolved gas levels downstream from the projects by 10 to 20% for a given spill flow. Deflectors were installed at Ice Harbor and John Day Dams and have provided gas abatement benefits in the upper portion of this range. Additional deflectors were installed in the end spill bays of Lower Monumental, McNary and Bonneville Dams. These additional deflectors have further improved the dissolved gas levels below these dams.

Spill Passage Conclusions

1. Estimates of spill efficiency and effectiveness for juvenile salmonids vary by dam, the percentage of river flow spilled, spill pattern, time of day, species (or run), and configuration of the dam. Spill effectiveness is generally between 1.0 and 2.0, but can range considerably higher at certain dams. There is a strong indication from studies at Ice Harbor Dam on the Snake River and The Dalles Dam on the lower Columbia River that above a certain level of spill, there is no gain in spill effectiveness and very likely a reduction. However, spill efficiency will continue to increase with the percentage of total river flow spilled.

2. Documented consequences of spill include increased fish passage efficiency (proportion of fish passing through non-turbine routes) and reduced migrational delays through forebays, tailraces, and reservoirs. Forebay residence time for downstream migrating juvenile salmonids is inversely related to spill.

3. Spill has the potential for reducing exposure risk to predation, high water temperatures, and disease. The presence of piscine and avian predators in forebays and detection histories of tagged fish in forebays suggest that delay of juvenile salmonids in dam forebays may lead to reduced survival.

4. Fish survival through spillways with deflectors or shallow stilling basins can be negatively influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spill bay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and thus total river flow, gate opening, and fish location when passing through the spill bay and under the control gate. Survival through spillways with deflectors or shallow basins can be considerably less than 0.98, a value typically used in hydropower system modeling exercises. Observations and lessons learned from spillway survival studies at The Dalles, Ice Harbor, and Lower Monumental Dams should be applied to other spillways with deflectors, to ensure that adequate spillway passage conditions are provided at these locations as well. Examples include Little Goose Dam, where survival may be lower than previously measured under some conditions, and possibly training spill associated with the Removable Spillway Weir at Lower Granite Dam and other weirs that may be installed in the future.

5. Tailrace residence time for juvenile salmonids passing through spillways is influenced by spill volume and pattern. Generally, spillway passage results in more rapid tailrace egress than bypass system passage. Because piscine predators prefer hydraulic cover such as eddies and backwaters, spill patterns that facilitate rapid juvenile salmonid egress from the spillway stilling basin through the tailrace likely increase survival.

6. In general, research results indicate that when daytime spill is provided, spillway passage of juvenile salmonids occurs at fairly constant rates, day and night. Juvenile salmonid migrations may be delayed if spill is managed based on powerhouse diel passage patterns.

7. (Summer spill conclusion - to be developed)

8. Results of GBD monitoring and research on juvenile salmonids indicate that incidents of high prevalence and severity of GBD signs and probable related mortality are associated with exceptionally high river flows and/or exceptional dam operation problems where powerhouse flows are limited. Under TDG cap conditions of 115% (forebay) and 120% (tailrace) signs of GBD are minimal or non-existent, with no apparent GBD related mortality.

JUVENILE SALMON PASSAGE THROUGH MECHANICAL SCREEN BYPASS SYSTEMS

Background

In response to concerns for the mortality additional dams were expected to impart on juvenile anadromous salmonids during their seaward migrations in the late 1960s, NOAA Fisheries (then the Bureau of Commercial Fisheries) began to investigate means to mitigate for the anticipated impacts. The development of systems to collect downstream migrants before they passed through turbines and the subsequent transport of the collected smolts around the remaining dams were two of the focal areas of original research during the earlier years, as they are nowadays. The original intent of the mechanical bypass systems then was to provide a method of collecting large numbers of downstream migrants at upstream dams for transportation to avoid the excessively high passage-related mortality of that period.

The contemporary mechanical-screen-bypass systems were developed over the next 30 years. The systems consist of a submersible fish screen within each turbine intake (for each turbine, there are three intakes and associated gatewells) which diverts migrants upward into a gatewell (Fig. 2). Once in the gatewell, a vertical barrier screen (VBS) concentrates and further guides the fish into the upper gatewell area where they pass through a submerged orifice and into a collection channel that travels the length of the powerhouse. The channel conveys fish and orifice flow from all gatewells directly to the river, or to dewatering facilities that reduce flow to approximately 30 cfs. This reduced flow can then be routed directly to the river or to secondary dewatering/separation facilities for subsequent separation, sampling, holding (for delayed truck or barge-loading), and/or direct loading onto barges.

Smolt monitoring facilities are located within key bypass systems and allow species composition, fish condition, run timing, and passage indices to be estimated. PIT-tagged fish can also be detected at these facilities, with time and date of passage noted and fish diverted for further evaluation, if desired. Monitoring at these facilities is continuous within the season and requires that fish be routed through the fish separators and sampling facilities. At other dams, such as Ice Harbor Dam, monitoring is periodic and is done to determine if mechanical problems are causing poor fish condition. Based on 2001-02 modifications at McNary Dam, secondary dewatering, separation, and sampling facilities can be bypassed completely by shunting collected fish to the dam's tailrace through a full-flow bypass pipe with PIT-tag detection capabilities. Similar systems are scheduled for installation at Ice Harbor and Lower Monumental Dams prior to the 2005 migration season.

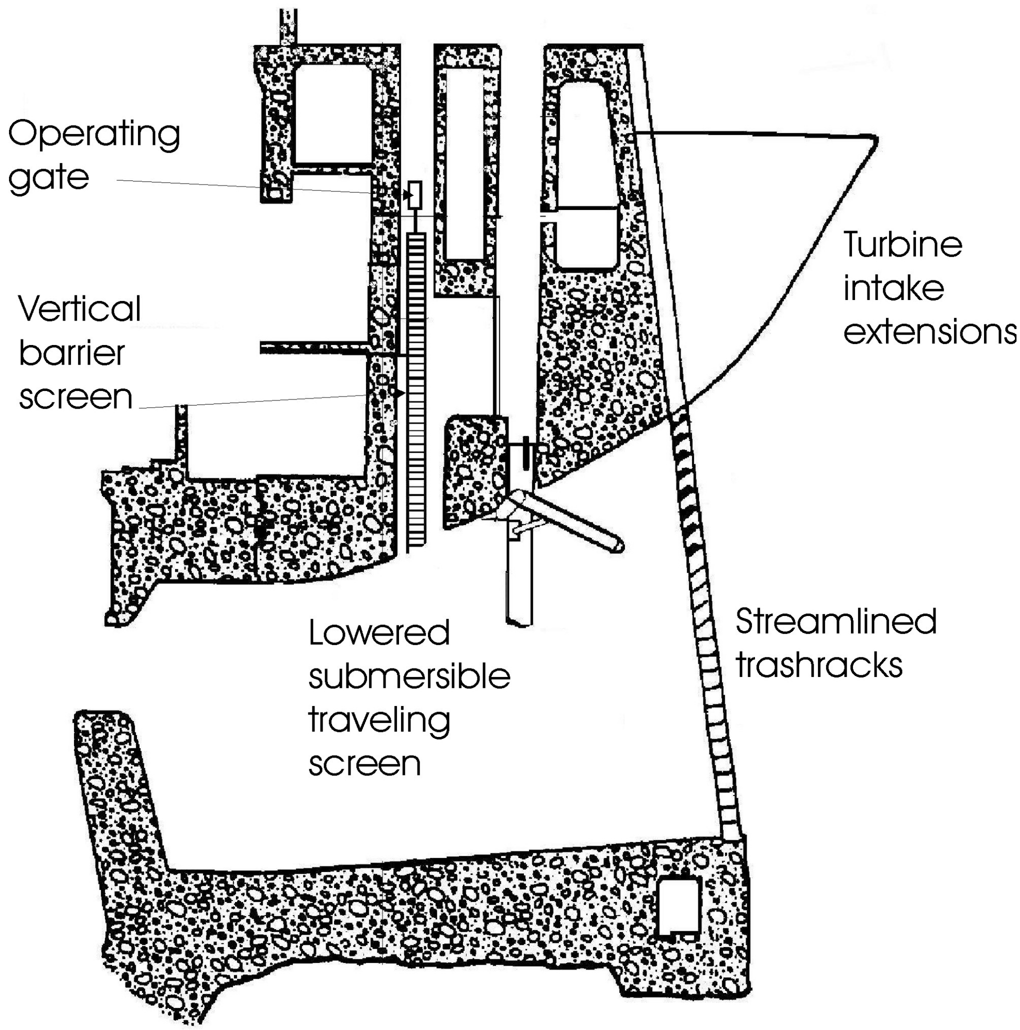

Figure 2. Cross section of the mechanical screen bypass system at the Bonneville Dam Second Powerhouse.

Two submersible fish screen designs are now in use to guide fish away from turbine intakes and into juvenile bypass systems at Columbia River hydroelectric dams, a submersible traveling screen (STS) and an extended submersible bar screen (ESBS). The STSs utilize a monofilament mesh screen that rotates around large rollers at the top and bottom of the screen. The screen is rotated periodically to allow flow passing through the screen to flush the mesh surface clean of debris. The STSs are currently installed at Lower Monumental, Ice Harbor, John Day, and Bonneville Dams. ESBSs are made of a fixed wedgewire screen material and have a brush sweep that is activated periodically to remove debris from the face of the screen. ESBSs are currently installed at Lower Granite, Little Goose, and McNary Dams. The Dalles Dam does not have a mechanical screen juvenile bypass system.

Mechanical screen bypass system design criteria are described in NOAA Fisheries Juvenile Fish Screen Criteria (NMFS 2004), COE bypass system design memorandums (COE 1995a, 1996a, 1999a), the COE Fish Passage Plan (COE 2004), and an intake design guidelines manual (ASCE 1995). NOAA Fisheries guidelines for locating and designing bypass outfalls are presented in NMFS (2004). Here we present essential fish passage information related to the development and operation of these systems.

Fish Guidance Efficiency

Results

Fish guidance efficiency (FGE) is the proportion of smolts passing through turbine intakes that are guided upwards into gatewells by the submersible fish screens. FGE is calculated as the number of guided fish divided by the total number of fish (guided plus unguided) passing through a turbine intake during a period of measurement (Brege et al. 1992).

FGE estimates vary with sampling method, species, rearing history, stock, fish condition (disease and smoltification), project, time of day, day, season, turbine unit, fyke net location, environmental conditions, and project operations. This spatial and temporal variability is likely related to complex interactions between biological and physical factors such as the arrival of different stocks at a dam throughout the season. Williams et al. (1996) attempted to clarify some of the mechanisms affecting FGE. However, FGE data based on fyke net estimates was generally limited to studies designed to compare FGE of existing vs modified (prototype) intake and vertical barrier screens. These typically involved different hydraulic conditions, and little could be concluded. Gessel et al. (1991) suggest that factors such as water temperature, turbidity, flow, photoperiod, physiological development, and predation by northern pikeminnow may affect FGE.

There are four methods of estimating FGE: 1) intake fyke nets and gatewell dip baskets, 2) hydroacoustics, 3) probability of detecting PIT tags, and 4) radiotelemetry. Early FGE studies utilized fyke-net frames beneath STSs to collect unguided fish in intakes (Krcma et al. 1986), and dip baskets (Swan et al. 1979) to collect guided fish in gatewells. Beginning in 1993, streamlined fyke-net frames and nets were designed to test extended screens and placed in gatewell slots located downstream from the guidance screen (Brege et al. 1994). The newly designed fyke nets and frame and placement downstream from the guidance screen minimized water resistance and possible FGE bias, which may have previously resulted from larger fish avoiding fyke collection. Gatewell dip-net recapture efficiency tests with yearling and subyearling chinook salmon produced recapture efficiencies of 95 to 100% (McComas et al. 1994, Brege et al. 1997a,b, 1998). More recently, FGE estimates have been obtained from the probability of detecting PIT-tagged fish (Smith 1997, Krasnow 1998, Anderson et al. 1998), and radiotelemetry (Adams et al. 1998a), and hydroacoustic (Ploskey and Carlson 1999) methods.

Differences exist among the FGE estimates derived from these methodologies, and each method has its advantages, disadvantages, and critical assumptions. For example, a strength of the fyke-net method is that it produces FGE estimates by individual species or life history type. On the other hand, the method generally measures FGE in only one gatewell of only one or two turbine units and for only relatively brief diel periods. The data tend to be highly variable and may not accurately represent even daily, much less seasonal, FGE over entire powerhouses. The method is probably better suited for comparing FGE during direct testing of various guidance technologies and configurations, with the possible exception of head-to-head comparisons between STSs and ESBSs. Recent tests of ESBSs at John Day Dam in 1999 suggested that gatewell dipping might not always recover all of the fish guided into a gatewell equipped with an ESBS (Brege et al. 2001). In this study, it was estimated that 20% of the guided fish were gatewell mortalities, and were not recovered by gatewell dipnetting because they had dropped out of the test gatewell prior to the commencement of dipnetting.

On the other hand, Ploskey and Carlson (1999) previously found strong seasonal correlations between counts derived from hydroacoustic and fyke-net methods for both guided and unguided fish at John Day Dam. However, hydroacoustics significantly underestimated both guided and unguided fish passage relative to the fyke-and dip-netting method. The two methods produced similar FGE estimates, but hydroacoustics undercounted both groups nearly equally relative to the netting method. In addition, hydroacoustics does not provide species-specific estimates of FGE, can count non-salmonid species and debris, and passage routes are generally not sampled completely. Hydroacoustic can, however, provide continual fish count estimates over long time periods.

The probability-of-detecting-PIT-tags method measures FGE of the entire powerhouse by species, but results are most reliable when groups of PIT-tagged fish pass during periods of near 0% spill. When groups pass during periods of relatively high spill, the method produces results dependent on the questionable assumption that spill index and detection probability have the same linear relationship throughout the range of observed spill values (Smith 1997).

Radiotelemetry has also been used to estimate FGE. Radio tags are implanted either gastrically or by surgery in fish that are generally larger than the population they represent. Both Adams et al. (1998a and 1998b) and Martinelli et al. (1998) concluded that surgical implantation was the preferred method for radio tags in most studies, though gastric implantation could be used in studies of short duration. Hockersmith et al. (2003) indicated that both tagging techniques would provide data comparable in quality to that derived from PIT tags in studies lasting 6 d or less. Radio-tagged fish are generally released well upstream of a particular dam and are therefore normally distributed relative to other fish by the time they arrive at the dam.

Williams et al. (1996) compared the probability of PIT-tag detection with fyke-net estimates of FGE at McNary Dam and suggested a pressure field created by the fyke nets located under the STSs biased yearling chinook FGE estimates upward. PATH (1998) developed a correction factor to adjust STS FGE estimates based on fyke-net position to improve the accuracy of the PATH retrospective model analysis for yearling chinook salmon. The correction factor was the ratio of FGEs derived at McNary Dam with the nets in the downstream slot compared to the upstream slot (i.e., directly beneath the STS). Krasnow (1998) estimated the correction factor to be 0.82. The validity of applying the FGE correction factor for yearling chinook salmon at McNary Dam to other intakes and species is unknown. For example, McNary Dam has a large, low velocity intake compared to most other powerhouse intakes. Monk et al. (1999a) acknowledged the PATH FGE adjustment but chose not to apply it to the data for Bonneville Second Powerhouse. In their view, the correction factor was not considered applicable to STS FGE at Bonneville Second Powerhouse because the intakes at McNary Dam and Bonneville Second Powerhouse are hydraulically different, nor would the correction have affected the conclusions of their analysis.

Estimations of FGE are inherently variable, regardless of the method used. This inherent variability makes it difficult to develop accurate and precise single-point estimates of FGE, and to use typical scientific format that would express FGE as a mean with a standard deviation. Even with this variability, single-point estimates of FGE are often used for modeling or management purposes. Table 3 presents values commonly used by PATH (Anderson et al. 1998) and NOAA Fisheries (Krasnow 1998) in modeling analyses. They reviewed the available data and developed point estimates of FGE for each project and certain species and rearing history.

NOAA Fisheries developed a spreadsheet model (SIMPAS) to evaluate benefits to fish survival associated with various FCRPS alternatives. FGE values used in SIMPAS differ slightly from Krasnow (1998). No single estimate of FGE by species and dam is universally accepted, and others in addition to those presented in Table 4 have been developed. To characterize the variability in the data, Table 4 also presents ranges in the actual daily FGEs measured through various sampling methodologies. Point estimates of FGE that are used to model the hydropower system should generally fall within these ranges.

Project operations can also affect FGE variability. For example, at Lower Granite Dam in 2002, Plumb et al. (2003a) radio tagged hatchery yearling chinook salmon and hatchery and wild steelhead to estimate passage metrics when the raised spillway weir (R.W.) was either on or off. Operation of the R.W. affected FGE differently for the three groups of fish. For hatchery yearling chinook salmon, total powerhouse FGE was 69% regardless of R.W. operation. However, for hatchery steelhead, FGE dropped from 90% when the R.W. was operating to 79% when it was not. The opposite trend occurred for wild steelhead, with the 77% FGE measured when the R.W. was operating increasing to 83% when it was not. For the entire powerhouse, seasonal FGE was 68% for yearling chinook salmon, 87% for hatchery steelhead, and 75% for wild steelhead. These values are similar to those reported for yearling chinook salmon and steelhead at this dam in Table 3 above. However, during these studies, some components of the prototype surface bypass collector were still in place, which may have affected hydraulic conditions and study results.

During 2003, Plumb et al. (2004) again radio tagged the same groups of fish at Lower Granite Dam to estimate passage metrics with the R.W. either on or with the dam spilling to the gas cap and with all surface bypass components removed from the forebay. In this study, seasonal FGEs were 82, 89, and 96% for yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively, and are higher than those reported in Table 3, especially for wild steelhead. During the R.W. treatment, FGEs were 80, 88, and 98% for yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. During the

Table 3. Fish guidance efficiency (FGE) at Columbia and Snake River dams for 1999 configuration.[d] These values are commonly used by PATH and NOAA Fisheries in modeling exercises.

Site (Screen type)	Species	PATH FGE (%)[a]	NOAA FGE (%)[b]
Lower Granite Dam (ESBS)	Yearling chinook	78	78
	Subyearling chinook	-	53
	Steelhead	-	81
Little Goose Dam (ESBS)	Yearling chinook	82	82
	Subyearling chinook	-	45
	Steelhead	-	81
Lower Monumental Dam (STS)			
	Yearling chinook	61	61
	Subyearling chinook	-	49
	Steelhead	-	82
Ice Harbor Dam (STS)	Yearling chinook	71	71
	Subyearling chinook	-	46
	Steelhead	-	93
McNary Dam (ESBS)	Yearling chinook	95	95
	Subyearling chinook	-	62
	Steelhead	-	89
John Day Dam (STS)	Yearling chinook	67	64
	Subyearling chinook	-	34
	Steelhead	-	85
The Dalles Dam (None) [c]	Yearling chinook	46	46
	Subyearling chinook	-	46
	Steelhead	-	40
Bonneville Dam			
Powerhouse One (STS)			
	Yearling chinook	41	38
	Subyearling chinook	-	16
	Steelhead	-	41
Powerhouse Two (STS)			
	Yearling chinook	43	44
	Subyearling chinook	-	18
	Steelhead	-	48

a Based on report to PATH from Anderson et al. (1998).

b Based on NMFS sensitivity run #1 (assumes $FGE_{ESBS} > FGE_{STS}$ for wild yearling chinook salmon).

c FGE values for The Dalles are based on passage through the ice and trash sluiceway.

d These estimates likely have range, but that range changes with a number of factors and is not easily estimated.

Table 4. Daily estimates of fish guidance efficiency (FGE) for existing conditions. Hydroacoustic estimates are not species or rearing history specific. Estimates come from a variety of sources, and include adjustments for fyke net position to yearling chinook salmon FGE with STSs.

Project (Screen type)	Species	Fyke net Min	Fyke net Max	Hydro-acoustics Min	Hydro-acoustics Max	Radio-telemetry Min	Radio-telemetry Max
Lower Granite (ESBS)	Yearling chinook			68[a]	93[a]	56[b]	62[b]
	Steelhead			68[a]	93[a]	84[b,c]	86[b,c]
	Subyearling chinook					42[b]	53[b]
Little Goose (ESBS)	Yearling chinook	67[d]	87[d]	17	100		
	Steelhead	88[d]	95[d]	61	100		
	Subyearling chinook						
Lower Monumental (STS)	Yearling chinook	43f	83[f]				
	Steelhead	58[f]	95[f]				
	Subyearling chinook	30[g]	40[g]				
Ice Harbor (STS)	Yearling chinook	53[h]	85[h]			50[i]	100[i]
	Steelhead	65[h]	95[h]				
	Subyearling chinook						
McNary (ESBS)	Yearling chinook	70[j]	96[j]	13	100		
	Steelhead	75[j]	97[j]	12	100		
	Subyearling chinook	45[j]	86[j]				
John Day (STS)	Yearling chinook	54[k]	78[k]			53[l]	84[l]
	Steelhead	65[k]	87[k]			67[l]	86[l]
	Subyearling chinook	13[k]	55[k]				
The Dalles	NA						
Bonneville Dam -First Powerhouse	Yearling chinook	21[m]	65[m]	15[n]	100[n]		
	Steelhead	27[m]	87[m]	15[n]	100[n]		
	Subyearling chinook	2[m]	43[m]	0[n]	100[n]		
Bonneville Dam -Second Powerhouse	Yearling chinook	22[m]	65[m]	0[n]	100[n]	29[o]	30[o]
	Steelhead	15[m]	70[m]	0[n]	100[n]	51[o]	52[o]
	Subyearling chinook	19[m]	62[m]	0[n]	100[n]		

a Johnson et al. (1999)
b Adams et al (1998)
c Includes ranges estimates for wild and hatchery steelhead
d Gessel et al. (1995)
e Anonymous (1996)
f Ledgerwood et al. (1987) and Gessel et al. (1993); range includes FGEs adjusted for fyke net frame position per Krasnow (1998)
g Ledgerwood et al. (1987)
h Brege et al. (1988); range includes FGEs adjusted for fyke net frame position and raised operating gate per Krasnow (1998)
i Pers. commun., Brad Eppard, NOAA Fisheries, February 2000
j McComas et al. (1995)
k Krcma et al. (1986) and Brege et al. (1987); range includes yearling migrant FGEs adjusted for fyke net frame position per Kransow (1998)
l Hansel et al. (1999a)
m Bonneville First: Monk et al. (1992a, 1993); Bonneville Second: Monk et al. (1994, 1995)
n Ploskey et al. (1998)
o Hansel et al. (1999b)

gas cap spill treatment, FGEs were slightly higher for yearling chinook salmon and hatchery steelhead, but slightly lower for wild steelhead, with measurements of 85, 90, and 95% FGE, respectively.

Despite the variability discussed above, some general FGE trends have been observed. Side-by-side fyke-net estimates of FGE with STSs and ESBSs generally indicate that FGE is statistically significantly higher with ESBSs (McComas et al. 1993, Brege et al. 1994). FGE for yearling chinook salmon at Lower Granite Dam generally increases over time throughout the migration season (Swan et al. 1990). A positive correlation was found between FGE and the level of smolt development exhibited by the migrant population (Giorgi et al. 1988).

With subyearling chinook salmon an opposite trend appears to occur; FGE generally decreases as the season progresses (Brege et al. 1988, Monk et al. 1999a). In the lower Columbia River, FGE of coho salmon is generally high and similar to steelhead, and sockeye FGE is generally lower than that of all other yearling migrants. FGE has been increased by a variety of adaptations to the basic STS, including extending the length of the screen from 20 to 40 feet (STS vs. ESBS), raising the operating gate which allows more flow up the gatewell, lowering STS screens to open the throat area, and the use of an inlet flow vane with ESBSs to direct more flow into gatewell slots.

Recent PIT-tag data also indicate that smaller Snake River yearling chinook salmon and steelhead smolts tend to be selected for guidance into bypass systems by submersible fish screens at higher rates than their larger cohorts, and that smaller individuals are also more prone to guidance multiple times as they migrate downstream through the FCRPS (see Zabel et al. in review or Williams et al. in prep.). Zabel and Williams (2002) showed that smaller PIT-tagged fish returned as adults at lower rates than their larger cohorts for some years. Together, these results indicate that mechanical screen bypass systems have, to varying degrees, the potential to be selective for species, life-history types, and other attributes such as size. Therefore, system managers should consider dam operations that utilize multiple routes to pass fish around dams to minimize any potential risk of reducing biodiversity.

Conclusions

1. There is no single best way to estimate FGE. Each of the four methods used has advantages and disadvantages, and each is better suited to certain applications or conditions than others.

2. Estimates of FGE are inherently variable, regardless of the method used. This variability makes it difficult to develop accurate and precise single-point estimates of FGE with high confidence. Even so, best estimates by dam have been developed. They are reported above and are used in regional modeling exercises.

3. Mechanical screen bypass systems have the potential to be selective for species, life-history types, and other attributes such as size. Therefore, system managers should consider dam operations that utilize multiple routes to pass fish around dams to minimize the risk of reducing biodiversity.

Orifice Passage Efficiency

Results

Once downstream migrants have been guided into gatewells by submersible fish screens, they exit into a bypass channel via an underwater orifice. It is important that fish not linger in gatewells for extended periods. Residence in this area can result in a variety of stresses, including those resulting from delay and crowding (particularly in gatewells equipped with STSs) and excessive descaling and injury (particularly in gatewells equipped with ESBSs).

Orifice passage efficiency (OPE) is the percentage of guided juvenile salmonids which exit a gatewell via the orifice in a given time period (usually 24 h). The most recent estimates of OPE at Lower Granite, Little Goose, McNary, and John Day Dams and at Bonneville First Powerhouse have been conducted by releasing either fin-clipped or PIT-tagged fish into the gatewell with the orifice open. With the fin-clipped fish, any remaining study fish are removed from the gatewell and counted after 24 h. The percentage that left the gatewell in 24 h is the OPE. With the PIT-tagged fish, OPE is calculated using the number exiting the gatewell as recorded by PIT-tag detectors in the bypass system.

The regionally accepted minimum level for OPE with STSs installed is 70%. However, because of the increased flows and higher turbulence in gatewells associated with ESBSs, OPE levels approaching 90% are probably more appropriate for gatewells with these guidance devices. At Columbia and Snake River dams, where OPE has been estimated with either an ESBSs or STSs in place, estimates have generally been greater than 70% for yearling and subyearling chinook salmon and steelhead, with the exception of yearling chinook at McNary Dam (Brege et al. 1998) and steelhead at Lower Monumental Dam (Gessel et al. (1993), both of which had lower OPE estimates with ESBSs and with much greater variability (Table 5).

Table 5. Most recent orifice passage efficiency (OPE) estimates for existing conditions (and prototype testing) at Snake and Columbia River dams.

Project	Species	OPE[a] (%)	Reference
Lower Granite Dam	Yearling chinook	95	Monk et al. 1997b
ESBS, 25-cm orifice	Steelhead	97	
Little Goose Dam	Yearling chinook	97	Gessel et al. 1996
ESBS, 25-cm orifice	--	--	--
Lower Monumental Dam[a]	Yearling chinook	88	Gessel et al. 1993
STS, 30-cm orifice	Steelhead	66	
McNary Dam	Yearling chinook	69	Brege et al. 1998
ESBS, 30-cm orifice	Subyearling chinook	79	
John Day Dam (ESBS w/ devices)	Yearling chinook	99	Brege et al. 2004b
Existing STS, 35-cm orifice	Subyearling chinook	97	
Bonneville Dam First Powerhouse	Yearling chinook	80	Monk et al. 1999b
Existing STS, 30-cm orifice	Subyearling chinook	98	
Bonneville Dam First Powerhouse	Yearling chinook	90	Monk et al. 1999b
Prototype ESBS, 30-cm orifice	Subyearling chinook	97	
Bonneville Dam second Powerhouse[b]	Yearling chinook	97	Monk et al. 2002
Modified screen system	Yearling chinook	94	
Bonneville Dam second Powerhouse[b]	Subyearling chinook	100	Monk et al. 2002
Modified screen system	Subyearling chinook	99	
Existing STS, 30-cm orifice			

a All estimates (except Lower Monumental) done with releases of fin-clipped fish; Lower Granite estimates are results of PIT-tagged and fin-clipped releases averaged together.

b Estimates made using PIT-tagged fish.

Although FGE and OPE are higher in gatewells equipped with ESBSs than those equipped with STSs, hydraulic conditions are also considerably more turbulent in the ESBS-equipped gatewells due to higher water velocities caused by more water being forced up the gatewells by the longer ESBSs. Additionally, the degree of gatewell turbulence at different dams varies with turbine discharge and gatewell volume. In recent studies at John Day Dam (which has relatively severe gatewell conditions), Brege et al. (2001) found that FGE and OPE were both high and within acceptable ranges in gatewells equipped with ESBSs. However, in a different test where fish were exposed to gatewell conditions over a longer period, gatewell-released marked fish were recovered at a high rate (99%), but also experienced 8% descaling and 2% mortality. These results suggest that, at some sites, improvements in FGE and OPE in gatewells equipped with ESBSs relative to STSs might be offset by increases in descaling and injury for the small percentage of fish that do not exit the ESBS gatewells rapidly. The fate of these fish is uncertain and may require additional attention, especially at McNary Dam where a 50% increase in turbine capacity is currently being evaluated. The primary issue with ESBSs is not delay, but the condition and survivability of the small percentage of fish that do not egress the turbulent ESBS-equipped gatewells quickly. Thus, there may have been a trade off between the two guidance systems. STSs have lower FGE and OPE than ESBSs, but might be better for those fish that are guided in terms of overall condition.

However, to correct the above problems at John Day Dam, the COE modified the porosity of VBSs and, as a contingency, added a gatewell flow-damping feature (which later evaluations in 2002 showed were not required). These adjustments were successful, as descaling and mortality rates returned to acceptable levels, averaging 4.0 and 0.1%, respectively, for yearling chinook salmon and 1.0 and 0.1% for subyearling chinook salmon, respectively (Brege et al. 2004).

There is no indication that fish diverted with ESBSs at Lower Granite Dam, where high numbers of fish are collected, are in poorer condition or suffer higher mortalities than expected. Descaling and injury of fish sampled by the smolt monitoring program and overall facility mortality are low. In addition, adult returns of PIT-tagged fish are consistently higher for fish collected and bypassed at Lower Granite Dam than from other dams, including those equipped with STSs (Williams et al. in prep.).

Two locations where increased gatewell flow may impact fish condition are McNary Dam and the Bonneville Dam Second Powerhouse. To address the potential for increased accumulations of fine debris and injury problems not anticipated with clean VBSs, methods to removed debris from the VBSs are being designed and tested at these locations.

Conclusions

1. At dams where OPE has been estimated with either an ESBSs or STSs in place, OPE estimates have generally exceeded the regionally acceptable values for yearling and subyearling chinook salmon and steelhead. Two exceptions were OPE for yearling chinook salmon at McNary Dam and for steelhead at Lower Monumental Dam. In both cases, OPE was lower than acceptable with an ESBS as the guidance device.

2. While OPE is generally higher for ESBSs than STSs, some earlier studies indicated that overall condition of juvenile fish might be poorer with the former. More recent studies on modified ESBSs suggested otherwise, as does some adult-return-PIT-tag data. Thus, ESBSs appear to guide higher percentages of smolts without concomitant increases in descaling and injury rates when appropriately-designed VBSs are coupled with ESBSs at specific dams.

Separators and Separation Efficiency

Results

Stress indices have repeatedly been shown to be elevated in yearling chinook salmon smolts when in the presence of steelhead smolts (Park et al. 1983, 1984; Congleton et al. 2000). Moreover, steelhead smolts, particularly those raised in hatcheries, are much larger and more physical than yearling chinook salmon smolts. Separation of these species at collection facilities is likely necessary to maximize survival of yearling chinook salmon smolts.

Separation of juvenile migrant salmonids by size is now an integral part of the juvenile bypass operations at FCRPS dams. Separators at Columbia River juvenile fish bypass facilities sort fish using an array of appropriately spaced bars oriented parallel to flow passing through a tank. This allows smaller fish to sound and pass between the bars, while excluding larger fish.

The strategy for using bars for separation falls into two categories, single- and two-stage, depending on the objective of the process. Single-stage separators are in use at Ice Harbor, John Day, and Bonneville Dams, where the primary purpose of separation is to monitor the condition of juvenile salmon and steelhead passing through the project bypass system. These units remove adult salmonids, large incidental species, and debris using "wetted" separation in which smaller fish (including salmonid smolts) fall between separation bars along with incidental flow, while large animals and most debris are carried across a short section of exposed bars into another flume for eventual return to the river. Smolts can then be sampled without concern for injury induced by larger adult and incidental fish and debris in the sample holding area. At John Day Dam, the adult fish separation bars are wetted by small low-pressure jets along their upper surface to facilitate fish movement along the bars. Following the separation and sampling process, facilities using single-stage separators bypass all fish to the river downstream from the dam. The Dalles Dam has no juvenile fish bypass system or separator.

Two-stage separators are used at McNary, Lower Monumental, and Little Goose Dams and are intended to separate large steelhead from smaller chinook salmon smolts, as well as remove adult salmonids, large incidentals, and debris prior to collection for transport. Size separation also allows selective bypass or transport of one or both smolt size-classes. The separators at these sites rely on 'wet' separation by keeping the fish completely submerged throughout the process. Wet separators depend on sounding behavior as an avoidance response to shallow conditions above the separation bars to achieve separation (Gessel et al. 1985). All fish are introduced to the upstream compartment along with transport flow from the bypass channel (Katz et al 1999). The smaller fish are filtered between bars in the upstream compartment, while larger smolts are removed in the second section. Large incidentals, adults, and debris pass through the unit to the third compartment for return to the river.

Because fish are continually submerged, wet separation was thought to be less stressful to fish. However, separation efficiency of operational wet separators has been usually less than 70% for small fish and varies considerably among years This is due to small fish passing over the bulkhead from the small to large fish section of wet separators where they are subsequently held and/or transported with larger fish. In addition, some fish hold under the bars for extended periods rather than exit expeditiously from separator units. With existing wet separator designs, especially those at Lower Monumental and McNary Dams, fish that delay in the wet separators become fatigued as a result of swimming in resistance to the hydraulic conditions within the unit.

The separator at Lower Granite Dam is unique in that a single-stage wet separation process is employed to segregate adult salmonids, large incidental species and debris from smaller fish. Presently, smolts are not separated by size. This system is scheduled for modification when with the entire Lower Granite Dam juvenile fish bypass facility is upgraded.

A research program was initiated in 1996 to evaluate potential improvements to existing wet separators, and to develop new separator concepts (Katz 1999, McComas et al. 2001a). These studies evaluated the effects of many physical separator designs, including separation bar length, slope, color, and spacing as well as effects of transport flow, water velocities through the separator, depth over separation bars, and exit orifice orientation and configuration (McComas et al 1998, McComas et al 2000, McComas et al 2001b). Other work considered parameters independent of physical design which may affect separation potential, such as ambient light and fish density.

Design criteria from those research efforts resulting in positive effects on separation efficiency and separator exit efficiency were incorporated into a separator insert used for comparison to the operational separator at McNary Dam (McComas et al. in prep b). In addition to enhancements to increase separation efficiency, the insert included a perforated-plate false bottom to reduce the volume available for residence under the separation bars, and a more efficient submerged exit-orifice configuration.

Evaluation of the insert against the McNary Dam operational separator over a series of 2-day replicates resulted in measurably higher separation efficiency values using the insert than for the McNary Dam operational separator condition, though the difference was only significant for large fish groups and the total salmonid catch. Using lights above the separator enhanced separation efficiency for all small salmonid groups although the relationship was significant only for the total small salmonid catch and for the total salmonid catch.

Since use of the insert did not result in a biologically significant increase in descaling or adverse stress levels compared to the McNary Dam operational condition, it was installed for use in the Lower Monumental Dam operational separator at the beginning of the 2002 juvenile migration. Over 2002 and 2003, using the insert has resulted in increased mean separation efficiency values for yearling chinook and sockeye salmon (McComas et al. 2003).

In addition to studies aimed at improving the function and design of existing operational separators, a second approach explored alternatives to the existing separator design. The most promising alternative concept to emerge from interagency brainstorming sessions was the high velocity flume (HVF) design. Under this strategy, smolts enter a section of open flume directly after transport from the bypass channel. While traveling at velocities not normally present in current operational separator designs (1-2 m s^{-1}) , smaller smolts could sound between appropriately spaced separation bars within the flume, effecting separation from larger smolts unable to fit between the bars.

Both groups would continue to different holding areas without the interruption caused by abrupt velocity reduction of incoming transport flow, and without migration timing delays, stress, and fatigue induced by combating flows within the separator.

Results using an evaluation HVF separator at McNary Dam during the 1997 and 1998 juvenile salmonid migration periods indicated that over 80% separation could be achieved for the total catch of all species combined (McComas et al. 2000, McComas et al. 2001). Based on these observations, a full scale prototype HVF separator was constructed at Ice Harbor Dam.

Results from cumulative evaluations of design and operational criteria using the prototype HVF separator from1999 through 2001 suggest that separation efficiency values of over 80% are possible for the total salmonid smolt catch, with moderate (5.3%) overall descaling, and virtually no timing delays in the separator unit (McComas et al. in prep b). However, most research to date has been conducted when fish abundance was relatively low. Studies are now proposed to test HVF separators under conditions of high fish abundances at Ice Harbor Dam. In addition, other studies have proposed a method for removing adults, large incidental fish, and debris prior to entering the smolt section of the HVF separator (McComas et al. in prep a). Although no high velocity flume separators are in operational use at juvenile bypass facilities in FCRPS dams, work is ongoing to complete the development of this concept as a possible option to, or replacement for, the current separator design.

Conclusions

1. Small yearling chinook salmon smolts appear to be stressed when in the presence of larger steelhead smolts. Separation may be necessary to reduce extended holding of small fish with larger fish, especially in the context of transportation.

2. Past research has demonstrated that separation efficiencies in excess of 80% can be attained with a high velocity flume separator concept. Research continues to further refine this method of separation for potential use in mechanical screen bypass systems.

Water Temperature Effects

Results

During summer, juvenile salmonids migrating through the Columbia and Snake Rivers encounter water temperatures that often exceed the 20°C (68°F) threshold mandated in the Washington State Clean Water Act (WAC 1992). Of greater concern, Columbia and Snake River temperatures exceeding the 25°C (77°F) upper incipient lethal water temperature for salmonids (Brett 1952) have been documented during the summer juvenile migration period. In recent years, considerable effort has been expended to investigate the effects of and to identify potential measures to decrease summer river temperatures.

The NMFS 2000 Biological Opinion (NMFS 2000) includes three Reasonable and Prudent Alternative (RPA) actions pertinent to the temperature issue and juvenile salmonids. The first, RPA Action 141, calls for the Action Agencies to investigate the relationships among elevated temperature, fish disease, and mortality during critical migration periods. The second, RPA Action 142, directs COE to identify and implement measures to address juvenile fish mortality associated with high summer water temperatures at McNary Dam. The third, RPA Action 143, calls for the Action Agencies, in consultation with other regional entities, to develop and coordinate a plan to model the effects of alternative Snake River operations (flow augmentation).

Several studies have addressed RPA Action 141 so far (effects of temperature on fish disease and mortality). In the summer 2001, researchers sampled subyearling chinook salmon at McNary Dam on the Columbia River to assess prevalence of the bacterial pathogens *Flexibacter columnaris* and *Renibacterium salmoninarum* (*Rs*; the causative agent of bacterial kidney disease) and to measure relative levels of heat shock proteins in liver tissue (Tiffan et al. 2003a). These authors reported:

1) of 181 fish sampled, 2 tested positive for *F. columnaris*;

2) of 61 fish necropsied, 8 had kidneys characteristic of infection by *Rs*;

3) of 120 fish from which kidney samples were collected and analyzed by an enzyme linked immunosorbent assay (ELISA), none were positive for *Rs*; and

4) results from heat shock protein sampling indicated that exposure to water temperatures above 22°C (71.6°F) evoked a strong peak in this physiological parameter.

In the summer 2002, Haskell et al. (2003) conducted a second year of study at McNary Dam, again assessing prevalence of bacterial pathogens and levels of heat shock protein. These authors reported:

1) no *F. columnaris* was observed in 599 fish randomly sampled, although 3 fish found during smolt monitoring operations tested positive for the pathogen;

2) low *Rs* levels were detected in 4 of 96 fish sampled; and

3) a mid-August peak in heat shock protein levels coincided with a water temperature exceeding 23°C (73°F).

Tiffan et al. (2003a) and Haskell et al. (2003) characterized the incidences of bacterial pathogens as low and recommend laboratory studies be conducted to quantify short- and long-term effects of elevated heat shock protein levels. In laboratory tests conducted by Mesa et al. (2002), effects of a single, acute thermal stress on survival, predator avoidance, and physiology of juvenile fall chinook salmon obtained from the Hanford Reach of the Columbia River were studied. They found that the thermally-stressed fish showed little direct mortality and no increases in vulnerability to predation. Marked physiological responses of fish to the temperature stress were noted, including transient increases in plasma cortisol, glucose, and lactate, as well as dramatic and persistent increases in levels of liver heat shock protein 70.

In response to a catastrophic loss of subyearling chinook salmon at the McNary Dam juvenile fish facility in summer 1994, the NOAA Fisheries 1995 BiOp required the action agencies to take measures to reduce the potential of a recurrence of the incident (NMFS 1995). In mid July 1994, the water temperature at the McNary Dam juvenile fish facility reached 20°C (68°F). A few days later, the facility experienced a catastrophic loss of subyearling chinook salmon over a period of several days, coincident with water temperatures exceeding 21°C (70°F). In prior years, large thermal gradients between operating and non-operating turbine units were observed and thought to be associated with instances of fish mortality. In the days leading up to the 1994 incident, although thermal profile data showed elevated water temperatures, no large gradients were present (Hurson et al. 1996). In a later analysis, Coutant (1999) suggested that the cause of acute summer mortalities at McNary Dam was cumulative exposure to high temperature water received over a period of several days. Occurrences of acute mortality on the scale of the 1994 loss over several days have not recurred at McNary Dam. For example, total juvenile fish facility mortality during the summer at McNary Dam was 2.2% during both 1997 and 1998, with a one-day peak mortality rate of approximately 8.0% in early July 1998 (Hurson et al. 1999). For the most recent 5-year period (1999 through 2003), summer fish facility mortality has averaged 1.0, 0.6, 0.7, 0.7, and 1.0% for the respective years, with no notable daily mortality peaks (data available at www.fpc.org).

Continuing concern over the McNary Dam temperature issue resulted in inclusion of RPA Action 142 in the NOAA Fisheries 2000 BiOp (NMFS 2000). RPA Action 142 directs the COE to identify and implement measures to address juvenile fish mortality associated with high summer temperatures at McNary Dam. Enhanced temperature monitoring has been in place at McNary Dam since the 1990s to monitor temperatures in the forebay, across the powerhouse, in gatewells, at locations within the collection channel, and at the fish monitoring facility. Temperature gradients within the system are known to occur when turbine units at the south end of the powerhouse are put into operation following an off-line period. Surface waters are warmer in the south forebay than in the forebay upstream from turbine units at the north end of the powerhouse. Turbine units at the south end of the forebay draw this warmer surface water into the bypass system via the gatewells, creating temperature differentials in the collection channel and increasing temperature in downstream portions of the bypass system. To the extent possible, COE limits occurrence of temperature increases through operational means, i.e., by restricting operation of the south end turbines (Units 1, 2, and 3), and by loading the powerhouse from the north end. Among the recommendations in RPA Action 142 is investigating the feasibility of developing a hydrothermal computational fluid dynamics model of the McNary forebay. Model development is currently underway through a contract with the University of Iowa (P. Ocker, COE, personal communication). The completed model will allow different operations (especially the 50% McNary turbine capacity increase) and potential structural mitigation measures to be evaluated.

In 2001, two large industrial mixers were installed in the forebay upstream from turbine units 1 and 2. Evaluation of the cooling effect of mixers on water column temperatures was conducted by Tiffan et al. (2003). Results indicated that the mixers were ineffective, decreasing temperature inside the mixer plume and in gatewells by only 0.5°C (0.9°F) and 0.1°C (0.2°F), respectively. In 2002, Haskell et al. (2003) operated turbine unit 1 experimentally to determine effects of turbine operation on water temperatures. Results of this study (Haskell et al. 2003) showed that turbine unit 1 gatewell temperatures increased by up to 3°C (5°F) upon starting the unit, followed by a gradual temperature decline lasting two or more hours. Haskell et al. (2003) released subyearling chinook salmon tagged with temperature-sensing radio transmitters into the bypass system. Tagged fish were exposed to thermal gradients up to 3°C (5°F) when turbine unit 1 was started, tagged fish resided in gatewells for a mean time of 7.8 h, and fish tended to hold in water less than 5 m deep within the gatewells. Haskell et al. (2003) concluded that fish condition, prior stress, and acclimation temperature could affect capacity to respond to temperature increases such as those observed in the gatewells of turbine unit 1 and recommended additional work to explore the effects on survival and performance.

Juvenile migrant salmonids experience high summer water temperatures during migration through the lower Snake River. The effect of elevated water temperatures on ESA-listed Snake River fall chinook salmon is a primary regional concern. This issue has been addressed through a number of biological field studies examining effects of flow augmentation and through RPA Action 143 of the NOAA Fisheries 2000 Biological Opinion (NMFS 2000).

Juvenile migrant salmonids experience high summer water temperatures during migration through the lower Snake River. The effect of elevated water temperatures on ESA-listed Snake River fall chinook salmon is a primary regional concern. This issue has been addressed through a number of biological field studies examining effects of flow augmentation, and through RPA Action 143 of the NOAA Fisheries 2000 Biological Opinion (NMFS 2000). Williams et al. (in prep.) provides additional information on the effects of water temperature on survival of juvenile migrants in the FCRPS.

Dauble et al. (2003) estimated that Snake River adult fall chinook salmon are currently restricted to about 20% of the Snake River habitat that was available prior to dam construction. Brownlee Dam, a high water storage dam in Hells Canyon, has altered annual temperature cycles below it in the lower Snake River. Connor et al. (2002) noted that the presently available spawning and rearing habitat is cooler and has lower growth potential than areas favored by the species prior to hydroelectric development. They suggested that slower development of fall chinook salmon to migrational size leads to delayed seaward migration, resulting in an unnatural exposure of smolts to elevated summer water temperatures in the Snake River.

A number of studies have investigated the biological consequences and temperature effects of flow augmentation. Flow augmentation using relatively cool water from Dworshak Dam is intended to increase migration speed and survival of smolts through the Lower Granite Dam reservoir. Connor et al. (1998) PIT-tagged rearing subyearling chinook salmon in the Snake River from 1992 to 1995 and monitored PIT tag detections at Lower Granite Dam, concluding that detection rate at Lower Granite Dam was positively related to mean summer flow and negatively related to maximum summer water temperature.

From 1992 to 2001, Connor et al. (2003a) used mark-recapture data to study migrational behavior of wild subyearling chinook salmon in the Snake River. Results suggested that flow augmentation increases the rate of seaward movement during one of four migrational phases and that augmentation likely prevents reversion to parr. Connor et al. (2003b) evaluated the results from wild subyearling chinook salmon tagged and released in the Snake River from 1998 to 2000 and concluded that survival of these fish generally increased with increasing flow and decreased with increasing temperature.

Tiffan et al. (2003b) tagged naturally-produced subyearling chinook salmon with temperature-sensing radio tags and tracked the fish in the Little Goose Dam reservoir on the Snake River during the summers of 1998 and 1999. They determined that temperatures selected by juvenile migrants were not significantly different from mean water temperatures and no areas of thermal refugia existed in the reservoir. Further, they suggested that augmentation with cold-water releases from Dworshak Dam may increase survival by lowering water temperatures by up to 4°C (7°F). Smith et al. (2003) studied survival and travel time of Lyons Ferry Hatchery subyearling chinook salmon from 1995 to 2000. These researchers determined that survival from release locations in the free-flowing reach of the Snake River to the tailrace of Lower Granite Dam was significantly correlated with flow, water clarity, and temperature. Survival decreased as flow decreased, as water clarity increased, and as temperature increased.

Smith et al. (2003) were unable to determine which of the three factors were most important, since the factors were highly correlated among themselves. They concluded that Snake River summer flow augmentation with relatively cool water will increase discharge while decreasing temperature of the river and will likely increase speed of seaward migration, thereby benefitting recovery of ESA-listed Snake River fall chinook salmon.

RPA Action 143 directs the Action Agencies, in consultation with other regional entities, to develop and coordinate a plan to model the effects of alternative Snake River operations (flow augmentation). Implementation of RPA Action 143 has occurred through the NOAA Fisheries Regional Forum's Water Quality Team. The Water Quality Team technical workgroup addressing RPA Action 143 is a cooperative effort, open to all regional entities. The RPA 143 Workgroup has met since March 2002 and has recently produced a comprehensive report detailing their progress toward meeting RPA Action 143 (NMFS 2003). Included in the report, and of particular interest to those considering the biological implications of Snake River flow augmentation, is an evaluation of biological needs including various life cycle stages of ESA-listed anadromous salmonids in the Snake River from Hells Canyon Dam downstream to the Columbia River confluence and in the Clearwater River from Dworshak Dam downstream to the Snake River confluence.

Other studies have also addressed RPA Action 143. Connor et al. (2000) described a method to forecast survival and cumulative percent passage for subyearling chinook salmon at a dam, thereby allowing managers to effectively time water releases. Cook et al. (2003) monitored thermal conditions at the confluence of the Clearwater and Snake Rivers and in the Lower Granite Dam reservoir and applied the results to a three-dimensional hydrodynamic and water quality model. They also applied a two-dimensional, laterally-averaged hydrodynamic water quality model to the three Snake River reservoirs downstream from Lower Granite Dam.

Conclusions

1. During summer, juvenile anadromous salmonids migrating through the Columbia and Snake Rivers encounter water temperatures that often exceed the 20°C (68°F) threshold mandated in the Washington State Clean Water Act. Temperatures exceeding the 25°C (77°F) upper incipient lethal water temperature for salmonids have also been documented during the summer juvenile migration period.

2. High summer water temperatures caused a catastrophic mortality within the juvenile collection facility at McNary Dam in summer 1994. The mortality was thought to have been the result of operating turbine units at the south end of the powerhouse which are supplied with warmer water. Since then, modifications to powerhouse operations and improved temperature monitoring have presumably prevented a recurrence, with average mortality rates during the most recent five summers ranging between 0.6 and 1.0%.

3. The two common fish pathogens, *F. columnaris* and *R. salmoninarum*, appear to have been of little concern relative to survival of subyearling chinook salmon within the bypass system at McNary Dam during 2 recent summers.

4. To date, a single laboratory study found that thermally-stressed subyearling chinook salmon showed little direct mortality and no increase in vulnerability to predation, even though test fish responded physiologically to the single, acute thermal stress.

5. In the Snake River, colder than normal water temperatures in spring delay development of subyearling chinook salmon resulting in later-than-normal summer migrations which coincide with increasing water temperatures. However, once migrating, these fish appear to respond positively in terms of their migration and survival rates due to flow augmentation from Dworshak Dam.

Effects of Bypass Systems on Smolt Condition and Survival

Results

Over the last 30 years, many improvements have been incorporated into existing juvenile bypass systems at Columbia and Snake River dams (Williams and Matthews 1995), and new systems have also been constructed. This work intensified during the 1990s, with existing bypass systems at Little Goose (1990), McNary (1994), and John Day Dams (1998) replaced with upgraded facilities, and completely new facilities built at Lower Monumental (1993) and Ice Harbor Dams (1996), and at the Bonneville Second Powerhouse (1999). Each of these new facilities was tested to locate and correct any areas within the structures, flumes, and pipes that might cause descaling, injury, or mortality to juvenile fish passing through them. In addition, the region's state and federal fisheries agencies monitor daily samples of the fish for descaling, injury, and mortality to ensure that these facilities continue to be operated in a manner safe for fish.

Because the 1993 Snake River smolt migration was the first where all hatchery spring/summer chinook salmon were adipose-fin clipped, we use that year as the starting point for examining fish condition (descaling and mortality) at each Snake River dam. Fish condition at the Snake River dams and at McNary Dam on the Columbia River is detailed in Hurson et al. (1994) and Hurson et al. (1998). More recent fish condition information is collected as part of the annual juvenile fish transportation program at each of the Snake River dams and at McNary Dam on the Columbia River (David Hurson, Pers. commun., U.S. Army Corps of Engineers). This information is summarized below.

The Lower Granite Dam juvenile fish facility was not replaced during the 1990s. Descaling rates from 1998 to 2002 averaged 2.7% for hatchery spring/summer chinook salmon, 1.5% for wild spring/summer chinook salmon, 2.8% for subyearling chinook salmon, 4.1% for hatchery steelhead, 1.7% for wild steelhead, 5.7% for sockeye salmon, and 3.0% for coho salmon (declared extinct in the Snake River in the early 1980s, but coho salmon were re-introduced for the 1996 juvenile migration). Mortality rates from 1998 to 2002 averaged 0.3% for hatchery spring/summer chinook, 0.3% for wild spring/summer chinook, 1.2% for subyearling chinook, less than 0.1% for hatchery steelhead, less than 0.1% for wild steelhead, 1.6% for sockeye, and 0.3% for coho salmon.

Descaling rates at Little Goose Dam from 1998 to 2002 averaged 6.2% for hatchery spring/summer chinook salmon, 4.9% for wild spring/summer chinook salmon, 3.2% for subyearling chinook salmon, 6.7% for hatchery steelhead, 3.5% for wild steelhead, 10.1% for sockeye salmon, and 6.4% for coho salmon. Mortality rates from

1998 to 2002 averaged 0.6% for hatchery spring/summer chinook salmon, 0.7% for wild spring/summer chinook salmon, 6.1% for subyearling chinook salmon, 0.3% for hatchery steelhead, 0.2% for wild steelhead, 2.0% for sockeye salmon, and 0.7% for coho salmon.

Descaling rates at Lower Monumental Dam from 1998 to 2002 averaged 3.1% for hatchery spring/summer chinook salmon, 2.5% for wild spring/summer chinook salmon, 2.3% for subyearling chinook salmon, 4.5% for hatchery steelhead, 2.7% for wild steelhead, 3.7% for sockeye salmon, and 3.9% for coho salmon. Mortality rates from 1998 to 2002 averaged 0.2 % for hatchery spring/summer chinook salmon, 0.2% for wild spring/summer chinook salmon, 2.3% for subyearling chinook salmon, 0.3% for hatchery steelhead, 0.2% for wild steelhead, 0.7% for sockeye salmon, and 0.1% for coho salmon.

The juvenile bypass system at Ice Harbor Dam was completed and evaluated in 1996. Hatchery steelhead and yearling chinook salmon released at two locations in the collection channel were recaptured and evaluated. Mortality and descaling for both species were less than 0.2% (Gessel et al. 1997). At this facility, the mechanical screen and bypass system operates continuously through the migration season while the sample facility operates intermittently to determine whether descaling and injury rates have increased or are excessive. While this provides a cursory examination of descaling and mortality annually, the small numbers of fish examined minimize the usefulness of any data collected.

The new juvenile fish facility at McNary Dam, the first Columbia River dam encountered by fish exiting the Snake River, became operational in 1994. The hatcheries in the Columbia River do not adipose-fin clip all of their spring/summer chinook salmon; therefore, the juvenile fish facilities at Columbia River dams cannot distinguish between hatchery and wild fish. Descaling rates at McNary Dam from 1998 to 2002 averaged 6.4% for spring/summer chinook salmon, 2.9% for subyearling chinook salmon, 5.7% for hatchery steelhead, 3.7% for wild steelhead, 9.6% for sockeye salmon, and 3.9% for coho salmon. Mortality rates from 1998 to 2002 averaged 0.2% for spring/summer chinook salmon, 1.0% for subyearling chinook salmon, 0.4% for hatchery steelhead, 0.3% for wild steelhead, 0.4% for sockeye salmon, and 0.4% for coho salmon.

Measures of bypass system survival at John Day Dam were comprised of observations of mortality at the sampling facility (Martinson et al. 2003) and data gathered during a bypass system evaluation (Absolon et al. 2000a.). Descaling rates at John Day Dam from 1998 to 2002 averaged 3.9% for yearling chinook salmon, 1.1% for subyearling chinook salmon, 1.9% for wild steelhead, 6.1% for hatchery steelhead, 2.5% for coho salmon, and 8.2% for sockeye salmon. Mortality rates from 1998 to 2002 through the modified bypass system reported by Martinson et al. (2003) at the John Day

Dam sampling facility averaged 0.5% for yearling chinook salmon, 0.2% for subyearling chinook salmon, 0.1% for wild steelhead, 0.3% for hatchery steelhead, 0.2% for coho salmon, and 0.8% for sockeye salmon.

The latest modifications to the juvenile bypass system at John Day Dam were completed in April 1998. Post-construction evaluation of the system was conducted in 1998 and 1999 (Absolon et al. 2000a, 2000b.). As part of this evaluation in 1998, hatchery chinook salmon yearlings and steelhead were released at various points within the system. Direct mortality during passage from the collection channel to the evaluation facility ranged from 0 to 1.5% for yearling chinook salmon. Direct mortality for three collection channel releases of steelhead ranged from 0 to 1.5%. In 1999, three groups of chinook salmon fry were released into the upstream end of the elevated flume and recaptured in the sample tank. No descaling or injuries were observed on any of the recaptured fish.

At Bonneville Dam, mortalities at sampling facilities in the first and second powerhouse were noted by Martinson et al. (2003). Descaling at the first powerhouse from 1988 to 2002 averaged 5.0% for yearling chinook salmon, 1.7% for subyearling chinook salmon, 4.2% for wild steelhead, 9.6% for hatchery steelhead, 3.6% for coho salmon, and 20.3% for sockeye salmon. From 1988 to 2002, mortalities at the first powerhouse averaged 0.2% for yearling chinook salmon, 0.4% for subyearling chinook salmon, 0.1% for wild steelhead, 0.1% for hatchery steelhead, 0.1% for coho salmon, and 0.5% for sockeye salmon.

The latest modifications to the juvenile bypass system at Bonneville Second Powerhouse became operational in 2000. Descaling observed at the second powerhouse from 2000 to 2002 averaged 2.5% for yearling chinook salmon, 0.5% for subyearling chinook salmon, 1.9% for wild steelhead, 5.5% for hatchery steelhead, 1.0% for coho salmon, and 6.6% for sockeye salmon. Mortalities observed at the second powerhouse from 2000 to 2002 averaged 0.8% for yearling chinook salmon, 0.5% for subyearling chinook salmon, 0.3% for wild steelhead, 0.4% for hatchery steelhead, 0.9% for coho salmon, and 2.0% for sockeye salmon.

Although these estimates give some measure of the upper limit of direct, immediate bypass system passage mortality, they cannot reflect mortality through the entire system since sampling locations are typically some distance upstream from the outfall. Also, some mortalities observed within a system may have resulted from prior injuries and conversely, some live fish observed in samples may die of passage effects later.

Today's juvenile bypass systems are vastly improved compared to those that existed during the 1970s and early 1980s. The descaling and injury and system mortality rates for all of the above facilities are substantially lower than those reported by Williams and Matthews (1995) which were reported primarily for fish collected at the then state-of-the-art facility at Lower Granite Dam. This is in spite of the fact that the criteria used to measure descaling are far more comprehensive today than during the earlier years. In addition, recent post handling and marking mortality rates are greatly reduced compared to those reported by Williams and Matthews (1995). Marsh et al. (1996, 1997, 2000, 2001, 2003, 2004) and Harmon et al. (2000) reported annual 24-h post handling and marking mortality rates ranging between 0.2 and 1.6%, with most values below 1.0%. These values differ little from those reported as bypass system mortality rates for fish that were bypassed, but not handled and marked.

Passage survival studies conducted by NOAA Fisheries at Bonneville Dam from 1987 through 1990 and in 1992 involved releases of differentially marked subyearling chinook salmon into various passage routes at Bonneville Dam, including the second powerhouse bypass system (1987 to 1990) and the first powerhouse bypass system (1992). These studies used fish identified with freeze brands and marked with coded-wire tags. Relative short-term survival for treatment groups was based on data from recapture of juvenile test fish downstream at Jones Beach (RKm 74) during seaward migration. Relative long-term survival for test fish using the various passage routes was to have been based on recoveries of coded-wire tags from fisheries, hatcheries, and spawning ground surveys.

Results from the above survival studies were reported in Dawley et al. (1988, 1989), Ledgerwood et al. (1990, 1991, 1994), and Gilbreath et al. (1993). Results from Bonneville Second Powerhouse tests conducted from 1987 to 1990 indicated that relative survival of bypass-released groups averaged 8.3% less than reference groups released in the tailrace immediately downstream from the dam, 7.6% less than turbine releases, and 17.3% less than groups released approximately 2 miles downstream from the dam (Dawley et al. 1996). Using a similar methodology, subyearling chinook salmon were released at the Bonneville Dam First Powerhouse in 1992 (Ledgerwood et al. 1994). Results indicated that relative survival of bypass-released groups was 11.8% less than turbine-released groups and 28.3% less than groups released approximately 2 miles downstream from the dam.

Due to the unexpected low survival of bypass-released groups, a separate evaluation was conducted at the Bonneville Second Powerhouse bypass system from 1990 to 1992 (Dawley et al. 1998a). In these studies, referred to as direct assessments of passage survival, a trap-net attached to the submerged outfall was used to recapture study fish immediately upon exit from the bypass system. Results indicated that the bypass system was not responsible for the considerable survival differences noted in the previous paragraph, although descaling, injury, and stress among release groups did increase as the distance traveled through the bypass system increased. It was hypothesized that increased stress and fatigue of fish traveling through the bypass system, in combination with a poor outfall location, resulted in high predation rates on juvenile salmonids exiting the bypass system. Hence, outfall location and configuration are important considerations for maximizing survival of bypassed juvenile salmonids.

Based on the results of these studies, the COE modified the bypass system at Bonneville Dam Second Powerhouse in 1999. The collection channel was modified to improve hydraulic conditions, a new dewatering facility was installed which uses floor and wall screens, a new 1.7-mile long conveyance pipe was installed, and outfalls were constructed at Hamilton Island, well downstream of Bonneville Dam. Gilbreath and Prentice (1999) evaluated the new bypass system. They found that none of the hatchery-reared steelhead which traversed the system died or were descaled or injured. For run-of-the-river steelhead, none showed adverse signs of passage effects other than a 0.3% mortality rate. Median passage time from the upstream end of the collection channel to Hamilton Island was about 3 h for hatchery-reared steelhead and about 1 h for run-of-the-river steelhead. The median passage time through the length of the collection channel was about 1 h for hatchery-reared steelhead compared to only a few minutes for run-of-the-river steelhead. For hatchery-reared yearling chinook salmon, none of the fish released were injured or descaled. However, mortality was 0.1%, which the researchers attributed to handling and tagging. For run-of-the-river yearling chinook salmon, descaling was 2.0% and mortality was 0.5% after passage through the new system.

Median passage time from the upstream end of the collection channel to Hamilton Island was about 46 min for both hatchery-reared and run-of-the-river chinook salmon. The median passage time through the length of the collection channel was about 4 and 7 min for hatchery-reared and run-of-the-river chinook salmon, respectively. During the summer smolt migration period, run-of-the-river subyearling chinook salmon were released to pass through the system. Descaling and injury was nil and mortality was 0.1%. Median passage time was 5 min through the length of the collection channel and 42 min from the upstream end of the collection channel to Hamilton Island.

Finally, recent PIT-tag data indicate that passage through multiple or individual bypass systems can reduce SARs of hatchery-reared, but not wild, smolts compared to those that were never detected in any bypass system during downstream passage. The exception is for smolts that were only detected at Lower Granite Dam (Sandford and Smith 2002). These fish consistently returned as adults at equal or higher rates than those not detected in any of the bypass systems during downstream passage. There is also evidence that juvenile bypass systems tend to select fish that are smaller than those represented in the general population (Zabel et al. In review), and that smaller fish survive at lower rates than larger fish (Zabel and Williams 2002). This confounds the causal relationship between decreased SARs and detection history at dams. A more detailed review of this subject is presented in the NOAA Fisheries Technical Memorandum Effects of the Federal Columbia River Power System on Salmon Populations (Williams et al. in prep.).

Conclusions

1. Contemporary mechanical screen bypass systems are vastly improved compared to the original systems that operated during the 1970s and early 1980s. Recent very low descaling and injury and system mortality rates are testimonials to the improved conditions for juvenile migrants using these passage routes.

2. Outfall location and configuration are important considerations for maximizing survival of juvenile salmonids that are bypassed back to the river below dams.

3. Smolt-to-adult return rates for PIT-tagged inriver migrants are related to bypass history. Smolts detected at dams other than Lower Granite Dam often return as adults at lower rates than fish not detected at any dams. For hatchery (but not wild) smolts, detection frequency is inversely related to SAR. A confounding factor is that smaller smolts with lower SARs tend to be more easily guided into bypass systems than larger smolts with higher SARs.

Effects of Bypass Systems on Blood Chemistry

Results

Stress agents or stressors are external and internal stimuli which induce quantifiable biochemical responses in higher animals including fish (Hane et al. 1966, Grant and Mehrle 1973). These physiological responses prepare animals for the "fight or flight response" which is the first stage of the general adaptation syndrome otherwise known as stress (Selye 1956). Stress, then, is an adaptive response by an animal to any of an innumerable number of environmental stressors. The response enhances the probability of survival; therefore, it is not necessarily negative, unless the stress is chronic in nature or the animal has been physically injured or forced to exhaustion. The primary stress response involves changes in blood plasma concentrations of cortisol and adrenaline, which influence levels of secondary indicators including lactate, glucose, liver glycogen, leucocyte count, free fatty acids, and the balance of various electrolytes (Mazeaud et al. 1977).

Several stressors related to passage through fish bypass facilities at hydroelectric dams have been shown to alter concentrations of stress indices in juvenile salmonids under experimental conditions. For example, elevated plasma cortisol and glucose levels have been associated with crowding and handling (Wedemeyer 1976, Congleton et al. 1984), descaling (Gadomski et al. 1994), acclimation temperature (Barton and Schreck 1987a), and confinement (Strange et al. 1978).

Under field conditions, Maule et al. (1988) among others demonstrated that juvenile chinook salmon plasma cortisol and glucose concentrations could increase cumulatively as the fish passed successive points in a bypass system, corroborating similar results from laboratory work with sequential handling (Barton et al. 1986, Congleton et al. 1999). However, Congleton et al. (1999) found that, generally, peak plasma cortisol levels in fish following handling experiments did not appear to be affected by repeated stressful experiences. They point out it is possible that fish in the multiple stress groups experienced some form of chronic, low-level stress, that was masked by the elevated pre-stress plasma cortisol levels in these groups.

Lactate, also used as a stress index, has been shown to increase in response to the stress of exertion (Mesa and Schreck 1989, Gadomski et al. 1994). As with glucose and cortisol, blood plasma concentrations of lactate can rise dramatically with exposure to this stressor, returning to pre-exposure levels after several hours following suspension of, or acclimation to, the stimulus.

Blood plasma indicators have been used routinely as stress indices during the fish bypass system evaluation process for upgraded facilities constructed at FCRPS projects since 1990. At each dam, blood samples were collected from chinook salmon and steelhead juveniles at successive points within the bypass system. Since blood plasma indicator levels in fish captured from a gatewell are similar to levels found in hatchery-reared (naive) smolts (Congleton et al. 1984), results were compared to samples taken from smolts collected concurrently from gatewells. This process was repeated several times through the smolt migration to include populations originating from different places and changes in other environmental factors. In all cases, blood plasma concentrations of cortisol, glucose, and lactate were measured as indices of stress resulting from passage through the facility. Mean levels of indicators (averaged across the entire smolt migration) are included in Table 6 by facility for each species evaluated.

Results from these studies varied by site. For yearling chinook salmon, there were significant increases in plasma cortisol and glucose concentrations at Little Goose (Monk et al. 1992b), Lower Monumental (Marsh et al. 1995) and John Day Dams (Absolon et al. 2000a) as fish passed from the gatewells through the sample tanks, while no significant differences were reported for any indicator levels from Ice Harbor (Gessel et al. 1997) and McNary (Marsh et al. 1996) Dams. Lactate levels increased significantly only at Little Goose Dam. Subyearling chinook salmon were evaluated only at McNary Dam and showed a change only for mean lactate values, which declined significantly before returning to gatewell levels in raceways.

Steelhead plasma cortisol concentrations increased significantly through all bypass systems except at McNary Dam, and significantly elevated levels of plasma glucose were recorded at Little Goose, Lower Monumental, and McNary Dams. Mean lactate concentrations in steelhead showed significant increases only at Little Goose and Lower Monumental Dams.

In general, blood plasma stress indices are within the normal range of expected values, as fish pass through current bypass systems. In cases where levels were measured following the bypass process (e.g., from raceways), stress indicator concentrations returned to near gatewell levels within a few hours of raceway residence.

Table 6. Recent juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) mean blood plasma stress indicator concentrations by juvenile fish facility sample location for COE operated hydroelectric projects on the Columbia and Lower Snake Rivers.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration: Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
John Day	1998	Absolon et al. (2000a)	yearling chinook salmon	gatewell	103.2	63.2	91.2
				pre-separator	151.6	76.2	82.6
				pre-sample tank	160.1	73.2	85.7
			steelhead	gatewell	98.8	88.2	98.6
				pre-separator	192.7	81.4	89.3
McNary	1994	Marsh et al. 1996	yearling chinook salmon	pre-sample tank	179.0	107.5	105.5
				gatewell	92.5	93.9	62.1
				post-dewaterer	97.5	97.1	74.8
				separator	102.4	91.6	65.3
				raceway (0-h)	89.5	87.7	66.9
				raceway (2-h)	98.4	93.1	61.5
				raceway (4-h)	84.7	86.2	57.1
				raceway (6-h)	79.8	88.3	52.3
				raceway (10-h)	92.3	103.2	61.7
			steelhead	gatewell	83.2	153.3	59.3
				post-dewaterer	84.4	108.2	49.9
				separator	90.5	109.7	59.9
				raceway (0-h)	101.2	132.7	72.4
				raceway (2-h)	108.0	137.3	62.4
				raceway (4-h)	86.9	132.7	59.6
				raceway (6-h)	75.8	131.2	53.4
				raceway (10-h)	100.9	161.5	62.6

Table 6. Continued.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
McNary	1994	Marsh et. al 1996	subyearling chinook salmon	gatewell	57.2	92.7	122.8
				post-dewaterer	82.6	85.1	75.5
				separator	75.9	88.2	77.7
				raceway (0-h)	84.4	73.1	114.2
				raceway (2-h)	70.8	82.0	82
McNary	1994	Marsh et al. 1996	subyearling chinook salmon	raceway (4-h)	75.6	80.9	78.4
				raceway (6-h)	68.1	87.0	77.3
				raceway (10-h)	88.3	89.2	87
Ice Harbor	1995	Gessel et al. 1997	yearling chinook salmon	gatewell	140.3	105.9	53.7
				pre-separator	140.7	95.2	59.2
				pre-sample tank	135.9	97.2	60.2
			steelhead	gatewell	101.0	131.4	51.4
				pre-separator	165.5	117.7	71.1
				pre-sample tank	188.8	112.9	65.2
Lower Monumental	1993	Marsh et al. 1995	yearling chinook salmon	gatewell	115.7	62.5	114.5
				post-dewaterer	144.6	68.9	73.4
				pre-separator	144.7	81.5	66.8
				raceway (0-h)	152.3	103.1	57.9
				raceway (2-h)	127.2	110.4	49
				raceway (4-h)	121.4	111.7	50.4
				raceway (6-h)	110.3	108.3	55.9
				raceway (10-h)	166.6	104.3	57.5
			steelhead	gatewell	84.4	119.8	54.6
				post-dewaterer	154.2	116.3	60.6
				pre-separator	184.0	127	72.7
				raceway (0-h)	138.6	147	52.1

Table 6. Continued.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration: Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
				raceway (2-h)	173.1	147.2	44.9
				raceway (4-h)	69.3	149.7	55.7
				raceway (6-h)	103.2	138	54.8
				raceway (10-h)	174.1	142.8	59.8
Little Goose	1990	Monk et al. 1992b	yearling chinook salmon	gatewell	75.7	96.5	56.4
				post-dewaterer	77.3	87.5	75.1
				pre-separator	112	86.7	72.6
				raceway (0-h)	140.7	107.8	71.0
Little Goose	1990	Monk et al. 1992b	yearling chinook salmon	raceway (2-h)	160.5	164.9	59.5
				raceway (4-h)	129.4	155.6	55.7
				raceway (6-h)	85.5	154.2	58.2
				raceway (10-h)	81.7	160.4	72.2
				pre-barge	79.4	109.2	55.6
			steelhead	gatewell	42.2	133	36.6
				post-dewaterer	114.5	126.3	67.5
				pre-separator	142.3	119.5	74.8
				raceway (0-h)	125.1	109.9	68.7
				raceway (2-h)	91.2	150.1	44.7
				raceway (4-h)	61	142.1	46.8
				raceway (6-h)	65.3	129.1	46.3
				raceway (10-h)	103.5	147	53.2
				pre-barge	125.4	140.8	51.4

Results to date suggest that the physiological effects of passage through fish bypass facilities on juvenile chinook salmon and steelhead are nominal, as measured by blood plasma stress indices, and follow a typical sequence for fish subjected to an acute stressor followed by acclimation to or removal of the stress (Wedemeyer 1976, Mazeaud et al. 1977). Several researchers have reported that effects of stress as measured by hepatic plasma indicators diminish within 24 h following removal of the stressor in a protected environment (Sharpe et al. 1988, Gadomski et al. 1994, Schreck and Knoebl 1997). For example, transported fish showed an initial increase in plasma cortisol levels immediately after loading onto a barge, but the effect abated to pre-loading levels after 3 h (Maule et al. 1988).

The relationships between physiological indicators of bypass-induced stress and subsequent survival during seaward migration are not well-documented or understood. There is evidence that short-term survival may be directly impaired as a result of stress in poor quality chinook salmon smolts. Under controlled conditions, Barton et al. (1986) demonstrated that multiple acute disturbances, similar to those encountered during the bypass process, resulted in cumulative physiological responses. Plasma indicator levels of healthy animals returned to control levels within 30 h with no mortality after three stress events, while the same treatment for unhealthy fish resulted in 50% mortality within 3 to 6 h after the third event.

Indirectly, bypass stress may also somewhat impair survival during subsequent migration. Barton and Schreck (1987b) found a positive relationship between metabolic rate and the plasma cortisol level in stressed fish. They concluded that even relatively minor events can reduce available energy stores in fish by as much as one quarter, leaving the animal with substantially fewer reserves to cope with future environmental challenges such as temperature adaptation, disease, and demands on swimming stamina. On the other hand, Mesa et al. (2000) found that imposition of an acute stressor on fish heavily infected with *Rs* did not lead to higher infection levels or increased mortality relative to infected but unstressed fish.

As with all animals, weaker, more vulnerable fish, are likely targets for predators. For example, Congleton et al. (1984) demonstrated a significant positive correlation between impaired predator avoidance and crowding stress resulting in plasma cortisol levels of 75-150 ng ml^{-1}. In another study, Gadomski et al. (1994) could not find a significant relationship between juvenile salmonid descaling and predation by northern squawfish, but noted there was evidence of increased predation of descaled fish compared to controls at higher descaling rates.

Conclusions

1. Passage through components of mechanical screen bypass systems induces physiological changes related to the general adaptation syndrome or stress in juvenile anadromous salmonids.

2. However, the physiological effects of passage through fish bypass facilities are nominal for juvenile chinook salmon and steelhead, as measured by blood plasma stress indices, and follow a typical sequence for fish subjected to an acute stressor followed by acclimation to or removal of the stressor. Unless exhaustion or physical injury are involved, the majority of bypassed fish are probably minimally affected by at least a single, and possibly several, stressful experiences.

3. There is both pro and con evidence that multiple stress experiences can cumulatively diminish survivability, particularly in animals of inferior quality. Some multiple stress events may inhibit survival while others may not. Post-stress survival likely depends upon which of an innumerable array of stressors are involved in combination with each fish's particular sensitivity to that stressor in terms of its overall condition, health, and environment at the time.

DIEL PASSAGE AND TIMING

Background

Beginning in the late 1960s, sampling from turbine intake gatewells and at smolt monitoring facilities within powerhouses of Columbia and Snake River dams consistently showed that the majority of smolts passed through the dams' powerhouses at night (Long 1968, Sims and Ossiander 1981, Brege et al. 1996), and that the timing of this pattern could be affected by holding behavior in gatewells and collection channels. Since then, hydroacoustic investigations and radiotelemetry data (for example, Johnson and Dauble 1995; BioSonics Inc. 1996, 1998; Ploskey et al. 1998; Vendetti and Kraut 1999) from most dams confirmed this as a consistent diel passage pattern and provided more details regarding specific hours of peak passage into turbine intakes.

The more recent studies also showed that peak passage hours differed among passage routes. For example, passage through sluiceways at Bonneville and The Dalles Dams generally peaked in early morning. Diel passage through spillways is more variable, paralleling powerhouse patterns at some dams, but showing high daytime passage and morning peaks at others. In the following sections, we review diel passage by project.

Lower Granite Dam

Since 1994, both radiotelemetry and hydroacoustic studies have been conducted in the forebay of Lower Granite Dam to assess fish behavior and efficiency relative to a surface bypass collector (SBC) in front of turbine units 4, 5, and 6. Johnson et al. (1998) found that fish passage into the SBC and spillway was higher during day hours than night hours. However, passage at the powerhouse pier nose and inside the turbine intake was reversed (Fig. 3). In 1999, spill occurred from 1800 to 0600, and highest peak spillway passage occurred at 2300. However, the diel distributions of fish passage were similar for the SBC and turbines, with peak passage occurring between 0600 and 1700 (Anglea 1999; Fig. 4). Anglea et al. (1999) found that nighttime spill efficiency was 57%, and that downstream passage was slightly lower at night, while abundance of smolt-sized fish was higher during the day.

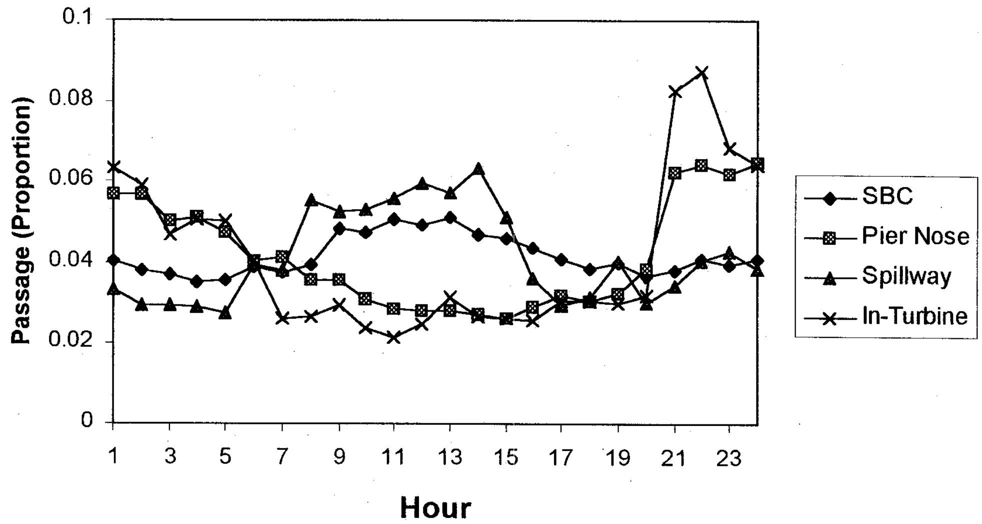

Figure 3. Diel distributions for surface bypass collector (SBC), pier nose, spillway, and in-turbine sample with fixed-location hydroacoustics at Lower Granite Dam, 1998 (from Johnson et al. 1998).

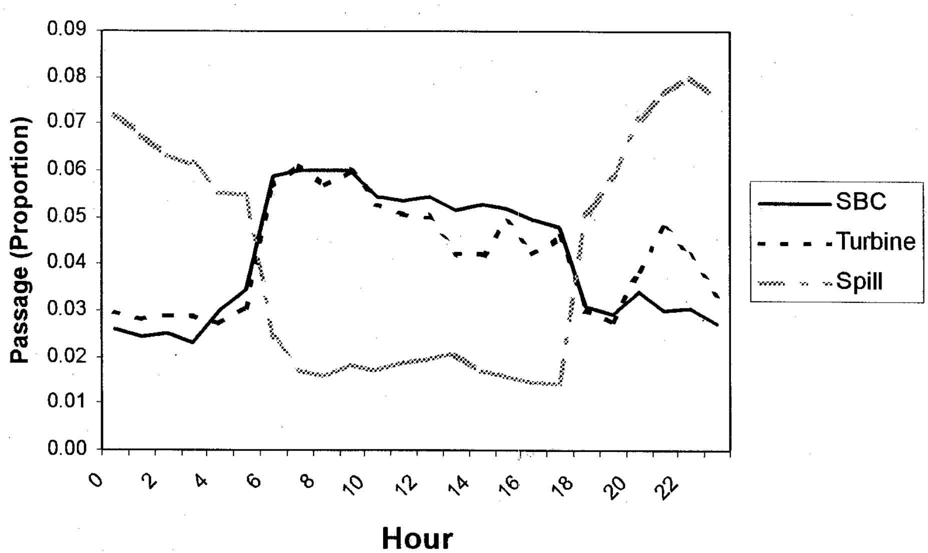

Figure 4. Diel distribution of fish passage for surface bypass collector, powerhouse, and spillway with fixed-location hydroacoustics at Lower Granite Dam, 1999 (from Anglea 1999).

Studies by Adams et al. (1997, 1999) tracked radio-tagged spring chinook salmon smolts as they approached the SBC. In 1998, from 66 to 78% of all radio-tagged fish entered the fish bypass (via the turbine intakes) between 1900 and 0600. With the exception of juvenile hatchery spring chinook salmon, most fish also entered the SBC during early evening and nighttime hours.

Seventy-six percent of wild steelhead and wild fall chinook salmon and 80% of hatchery steelhead entered the SBC between 1900 and 0600. A summary of all radiotelemetry and hydroacoustic studies conducted to evaluate the effectiveness of the SBC, including all information related to diel passage timing and movement can be found in Anglea et al. (2002).

Adams et al. (1997, 1999) also compared forebay residence times of hatchery chinook salmon, hatchery steelhead, and wild steelhead for the period 1994 to 1998. Flow and spill varied throughout the period, and were generally highest in 1997, and the peak spill in May was approximately 115 to 120 kcfs. Comparing forebay residence times for high flow years (1996 to 1998) to the lower flow years (1994 and 1995) suggests that in general, high flows and increased spill volume and hours reduced forebay residence time. For example, hatchery steelhead median residence times were 14.2 h and 26.7 h in 1995 and 1994, respectively, compared to 0.7 to 4.0 h from 1996 to 1998. Hatchery yearling chinook median residence times were 6.8 and 5.0 h in 1995 and 1994, respectively, compared to 1.0 to 1.9 h from 1996 to 1998. Wild steelhead median residence times showed little difference between years and ranged from 0.7 to 3.5 h between 1995 and 1998.

In an attempt to improve surface bypass at the dam in 2001, the COE installed a removable spillway weir (R.W.) in spillway 1. Using radiotelemetry in spring 2002, Plumb et al. (2003a) reported that route of passage at the dam varied depending upon the time of day. During the day (0500-1959), 60% of yearling chinook salmon passed the dam via the R.W., 20% passed via spill, and 20% passed via turbine routes. For hatchery steelhead, 73% passed via the R.W., 6% passed via spill, and 21% passed via turbine routes. For wild steelhead, 69% passed via the R.W., 14% passed via spill, and 17% passed via turbine routes. In contrast, passage decreased through the R.W. and increased through the spill and turbines for all three fish groups during night. For yearling chinook salmon, 49, 26, and 25% passed via the R.W., spill, and turbine routes, respectively. For hatchery steelhead, 38, 22, and 40% passed via the R.W., spill, and turbine routes, respectively, while for wild steelhead, 42, 25, and 33% passed via the R.W., spill, and turbine routes, respectively.

In 2003, Plumb et al. (2003b) confirmed the above trends. As they approached the dam, smolts were distributed shallower during daytime and deeper during nighttime (Plumb et al. 2003b). Hence, they are more apt to pass the dam through the deeper passage routes afforded by turbines and spillways at night than during day. Performance of the R.W. was optimal during the day, regardless of species or rearing type.

Little Goose Dam

In 3 years of research by Vendetti and Kraut (1999), passage of radio-tagged juvenile subyearling chinook salmon showed a slightly different diel pattern for passage through the powerhouse at Little Goose Dam (Fig. 5). Peaks in the number of detections were observed between 0500 and 0600 and again in the evening between 1800 and 2000, with the evening peak being the larger and longer of the two.

Lower Monumental Dam

To assess the downstream migrational patterns of smolts passing the dam and to estimate the effectiveness of spill in passing migrants, hydroacoustic investigations were conducted at Lower Monumental Dam from 1986 through 1989 (Wright et al. 1986, Ransom and McFaden 1987, McFaden 1988, Ransom and Sullivan 1989). As at other dams, turbine passage rates were highest during nighttime, with a peak at 2300. During the 4 years of study, nighttime project passage (powerhouse and spill) ranged from 70 to 84%.

Spillway operation varied over the 4 years of tests. In 1986, spill varied from just nighttime spill (1800 to 0600) to a constant 24-h spill. Examination of diel passage during these different flow regimes suggested that both fish behavior and dam operations influenced the timing of spillway passage. During a period when spill was relatively constant throughout the day, a pronounced peak in passage occurred at 2200. However, this evening peak was enhanced during periods when spill was off during daylight hours and started at 1800. In studies from 1987 to 1989, the spillway was only operated from 1800 to 0600, and highest passage rates occurred at 2300 and declined steadily from 2300 to 0600.

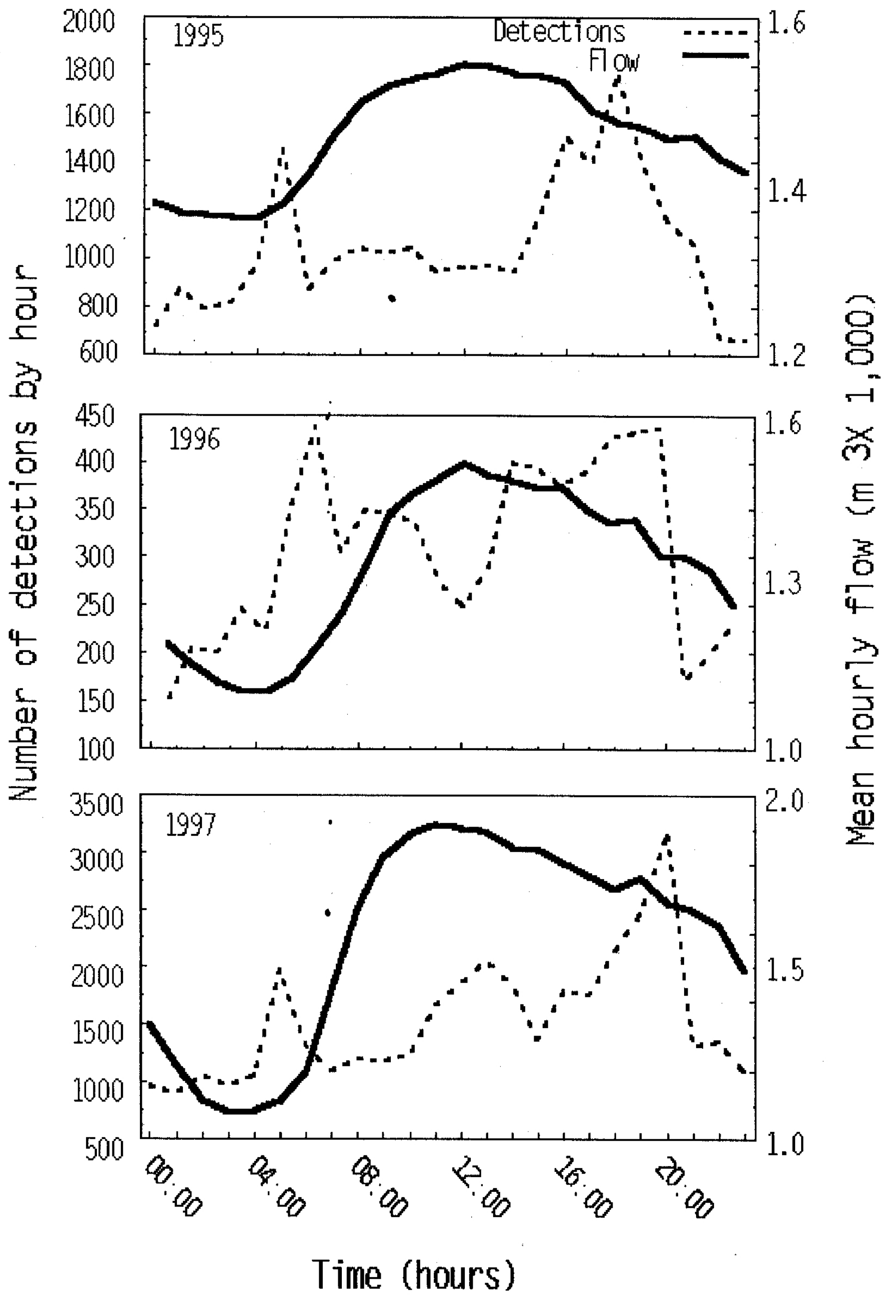

Figure 5. Total number of detections over the entire study period vs. mean hourly discharge at Little Goose Dam, 11 July-24 August 1995, 17 July-24 August 1995, 17 July-26 August 1996, and 15 July-23 August 1997 (from Vendetti and Kraut 1999).

Ice Harbor Dam

Three years of hydroacoustic investigations at Ice Harbor Dam revealed diel passage patterns similar to other Columbia and Snake River dams (Johnson et al. 1983, Ransom and Ouellette 1988). Most migrants passed the dam at 2300. Sluiceway diel passage rates were highest from 0600 to1300. Turbine passage rates were highest from 2100 to 0600.

During all 3 years of study, hourly passage rates through the spillway were more variable than through the turbine units or sluiceway. Generally, spillway passage rates were low in the early morning and then increased steadily to a peak at 1200. The rate then declined rapidly, reaching a low point at 1700, followed by a secondary peak at 2100 (only slightly lower than the peak at 1200).

In 1999, a radiotelemetry study of yearling chinook salmon passage was conducted at Ice Harbor Dam to determine tailrace egress and routes of passage under varying levels of spill and powerhouse flow (Eppard et al. 2000). At 1800 each day, powerhouse flow was reduced while spill was increased to the maximum level based on dissolved gas levels, until 0600 h the following day. The test fish were released in the tailrace of Lower Monumental Dam each morning (0800) via the bypass outfall. Receivers were positioned 1 km above Ice Harbor Dam and across the powerhouse and spillway, in the juvenile bypass channel, and on each submersible traveling screen. Each individual fish could be timed from the study entrance line through the passage route. Of the 580 fish detected 1 km above the dam, diel passage was fairly evenly distributed. A total of 302 and 278 fish passed the project during the day and night, respectively, although release location may have affected these results. Spilled fish had a lower forebay residence time, and fish first detected after dark had a lower forebay residence time than those first detected during daylight hours.

McNary Dam

No hydroacoustic or radiotelemetry studies have been conducted that provide a robust source of diel passage information at McNary Dam. Studies of orifice passage efficiency (OPE) using an orifice trap provide information on hourly passage from the gatewell(s) sampled. McComas et al. (1997) using an orifice trap found that passage from gatewells into the juvenile bypass channel appeared heaviest within a few hours of dawn and dusk, with the dusk peak having generally larger numbers of fish. Orifice trap data does not provide information on when fish first arrived in the forebay or entered the gatewell.

John Day Dam

Diel passage patterns have been reported as part of the smolt monitoring program at John Day Dam since the 1970s. This sampling, done mainly in gatewell Slots 3A and 3B, has shown that all species of juvenile salmonids tended to pass through the John Day Dam powerhouse during hours of darkness (Brege et al. 1996). In more recent years, further observations by the have confirmed that passage occurs predominantly from 1800 to 0600 (Martinson et al. 1998; Table 7).

Giorgi and Stevenson (1995) reviewed all gatewell sampling, hydroacoustic, and radiotelemetry data from 1980 to 1989. They concluded that even though none of the reports reviewed offered robust estimates of diel passage, there was consistent agreement among all evaluation tools and across many years. The data indicated that smolts at John Day Dam exhibit a strong tendency to sound and pass through deep passage entrances during nighttime hours. Both the hydroacoustic and radiotelemetry data corroborated the gatewell sampling and also showed that timing of spillway passage through the deep spill intakes (47 to 58 ft below normal operating pool) paralleled powerhouse passage.

One factor that could influence passage timing measured at the dam is the release location of the radio-tagged fish during the earlier and even some more recent studies. In 1996, Holmberg et al. (1998) saw diel passage patterns similar to those summarized by Giorgi and Stevenson (1995). However, the test fish were released only a short distance upstream (8 km) from the dam. In 1997, Hensleigh et al. (1999) observed a similar pattern for fish also released a short distance upstream from the dam. In contrast to previous years, they saw no apparent diel pattern for fish released at McNary Dam. They also reported that, with high spill volumes in 1997, 50 to 75% of radio-tagged fish passed through the spillway, as compared to roughly 40% in previous years.

In 1997, BioSonics (1999a) reported higher numbers of fish passing the dam at night based on hydroacoustic studies. They estimated that 54 to 89% of the fish passed through the spillway. Also, during the spring when spill level was similar day and night, they observed that fish passed the spillway at a rather uniform rate. In 1999, Hansel and Beeman (1999) saw differences in species response to dam operations. Steelhead generally passed at night regardless of spill discharge. Further analysis of the data suggests that <200mm (primarily wild) steelhead did readily pass the spillway throughout the diel period (Gary Fredricks, NOAA Fisheries, Pers. commun., March 2000). Yearling chinook salmon appeared to readily pass the project if daytime spill was provided. Information on John Day Dam spill effectiveness and efficiency is discussed in the Spill Efficiency and Effectiveness section.

Table 7. Percent night passage (1800-0600) for each season at John Day Dam, 1985 to 1997 (Martinson et al. 1998).

Year	Yearling chinook	Subyearling chinook	Wild steelhead	Hatchery steelhead	Coho	Sockeye
1985	83.2	83.7	N/A	N/A	91	86.8
1986	75.5	80.1	N/A	N/A	95.9	81.9
1987	84.5	85.4	93.6	85.6	95	94.9
1988	80	80.7	80.8	70.3	83.9	87.1
1989	86.4	86.2	73.6	79.4	93	79
1990	79.7	84.4	76.3	94.8	95.6	85
1991	89.9	77	91	92.3	96.2	83.6
1992	82.8	78.7	95.3	91.5	96	94.9
1993	83.3	87.8	83.4	80.7	95.1	86.5
1994	80.9	68.1	91.6	81.4	92.2	94.5
1995	80.7	79.7	87.9	75.8	91.5	79.5
1996	68.6	70	81.6	74.7	80.2	65.6
1997	62.6	73.1	67	70.6	73.7	59.6
AVERAGE	79.8	79.6	83.8	81.5	90.7	83
MIN	62.6	68.1	67	70.3	73.7	59.6
MAX	89.9	87.8	95.3	94.8	96.2	94.9

Time to pass the project is another important consideration. In 1995, Sheer et al. (1997) estimated that forebay residence time of spring chinook was 10 h during conditions of low spill (< 14 kcfs). For 1996, Holmberg et al. (1998) reported delays of less than 1 h during moderate spill conditions (47 to 125 kcfs). In 1997, Hensleigh et al. (1999) observed forebay residence times of 0.3 h when spill discharge exceeded 300 kcfs.

To summarize, data collected during the 1980s suggested there was a strong and consistent tendency for fish to pass the project at night. However, it is difficult to compare results from recent and earlier studies, due to differences in sample sizes, release points for tagged fish, and radio-tagged fish release timing. Based on radiotelemetry and hydroacoustic study results since 1997, it appears that yearling migrants, especially yearling chinook, will readily pass the spillway during the day if spill volumes are 30% or greater. Daytime spill volumes other than 30% have not been tested using recent release protocols for radio-tagged fish.

More recently, Hansel and Beeman (1999) found that juvenile steelhead generally passed the dam at night regardless of the spill discharge when they arrived. Yearling chinook salmon passed similarly when arriving during a daytime spill discharge rate of 68%, but during 30% daytime spill, they passed at that time. Fish arriving at night generally passed at night.

According to Anglea et al. (2001), radiotelemetry studies conducted in 1999 and 2000 and hydroacoustic studies conducted after 1999 were the only studies that collected sufficiently reliable passage and survival data for studies conducted at John Day Dam. They also reported it appeared that a majority of juveniles passed the dam at night (especially for steelhead where often over 90% passed at night regardless of treatment). They also reported that the addition of day spill increased the proportion of juvenile salmonids passing the spillway during the day (especially yearling chinook salmon in 2000).

The Dalles Dam

Diel passage through the powerhouse at The Dalles Dam is similar to that seen at other Columbia and Snake River dams. Both gatewell dipping (Long 1968) and hydroacoustics (Magne et al. 1983, Steig and Johnson 1986, Johnson et al. 1987, BioSonics Inc. 1996) documented that the majority of all salmonids entered gatewells between 1900 and 0700. In studies conducted by BioSonics Inc. (1996), both spring and summer migrants exhibited peak passage during hours of darkness.

As with Bonneville Dam, diel passage through the sluiceway does not seem to follow the nighttime passage pattern. Early studies by Nichols (1979) and Nichols and Ransom (1980, 1981) reported that sluiceway passage peaked during daylight hours, typically around mid-day. More recent hydroacoustic studies have also found that average daylight passage through the sluiceway was the predominant pattern at The Dalles in the spring. During the summer period, passage rates through the sluiceway also showed low night passage, but the peak was during the afternoon rather than morning. After reviewing all available literature, Giorgi and Stevenson (1995) concluded that regardless of the sampling approach employed, during spring, juvenile salmonids pass via the sluiceway at The Dalles Dam through most of the 24-h period, with peak passage occurring during daylight hours.

There are few measures of diel passage at The Dalles Dam spillway, because in most of the studies conducted there, spill was only provided at night and did not span a 24-h period. However, in studies conducted in 1996 by BioSonics Inc. (1996), spill levels were maintained for 24-h periods and slightly higher morning passage rates via spill were found during the spring. This morning peak was even more pronounced during the summer migration. In 1999, Ploskey et al. (1999) found that diel distribution of fish passage during the spring through the spillway was similar between the 30 and 64% spill treatments. The proportion of spillway fish passage was relatively uniform except for a substantial peak between 2000 and 2100. During the summer fish passage through the spillway was again fairly uniform except for peaks at 0600-0700 and 2000-2200 during 30% spill, and from 1800-1900 during 64% spill.

More recently, Hansel and Beaman (1999) examined FPEs and spill and sluiceway passage efficiencies of yearling chinook salmon and steelhead at the Dalles Dam. With the exception that the FPE of juvenile steelhead was significantly greater during the day than night during the 30% spill discharge (95 vs 86%, respectively), neither FPE nor spill passage efficiency differed significantly between day and night for either species. However, differences between diel passage conditions did affect spillway passage location. During the adult spill pattern, radio-tagged fish passed mostly through the southern end of the spillway, whereas during the juvenile spill pattern they passed predominantly through the northern end. Median residence time in the near-dam forebay area was generally less than 0.4 h for both species, but juvenile steelhead during the daytime 30% spill discharge had median residence time of 2.3 h.

Using radio tags, Beeman et al. (2000a) found that residence times were significantly longer for steelhead arriving during the day than at night, and that steelhead greater than 200 mm in length had significantly shorter residence times than smaller steelhead. Presumably, this reflects a behavioral difference between wild and hatchery steelhead, since the former tend to be smaller. In a similar study on subyearling chinook salmon, Beeman et al. (2000b) reported total project diel passage was 59% and 41% during day and night, respectively.

With hydroacoustics, Moursand et al. (2001) used relative passage rates between the major routes of turbine, sluice, and spillway to examine temporal differences in passage. Turbine passage peaked at night in the spring, but that peak shifted to afternoon by summer. Spillway passage showed a peak in the morning hours, and this trend remained through the summer. There was a pronounced trend for fish to preferentially pass through the sluice during the day rather than at night. This trend was clear in both spring and summer.

Bonneville Dam

Passage patterns at Bonneville Dam are more complex than at other dams because there are three separate structures, two powerhouses and an unattached spillway. There are also two passage routes at each powerhouse, the turbines and ice/trash sluiceway. For this reason, the available information is provided separately for each powerhouse and the spillway.

First Powerhouse

Gessel et al. (1986) dipped gatewells over 24 h during six periods throughout the spring migration and observed peaks in passage shortly after dawn and dusk, with the evening peak being typically much higher. From 1992 to 1995, the Smolt Monitoring Program sampled juvenile migrants moving through the downstream migrant channel on a 24-h basis (Martinson et al. 1999). During this time, passage for all species increased at dusk, at about 2000, and peaked at 2200 (Table 8). Since 1995, the Smolt Monitoring Program has sampled for 8 h per day only (from 1600 to 2400) and has reported the typical dusk peak in turbine passage observed at Snake River and lower Columbia River dams (Martinson et al. 1996, 1997, 1998).

In 1998, Martinson et al. (1999) observed that the 8-h passage patterns of tule and bright stocks of subyearling chinook salmon followed the same general pattern as spring migrants with only slight differences. Increases in tule passage began earlier, at about 1800, had a smaller peak at 2200, then averaged a lower percent of total passage for the remaining hours. Upriver bright passage resembled the spring migrants, with a larger, more abrupt increase at 2200 and a gradual decline in passage thereafter.

Table 8. Percent night passage (1800-0600) for 1992 to 1995 at Bonneville Dam First Powerhouse (Martinson et al. 1999).

Year	Yearling chinook	Subyearling chinook	Wild steelhead	Hatchery steelhead	Coho	Sockeye
1995	52.8	65.8	68.3	62.9	70.7	56.2
1994	49.6	52.4	52.2	53.1	66.7	74.6
1993	43.2	56.2	67.1	62.4	68.1	63.6
1992	52	44	62.3	61.3	60	69
MEDIAN	50.8	54.3	64.7	61.9	67.4	66.3
MIN	43.2	44	52.2	53.1	60	56.2
MAX	52.8	65.8	68.3	62.9	70.7	74.6

Hydroacoustic data from Ploskey et al. (1998) also showed that mean hourly smolt passage into turbines at Bonneville First Powerhouse was higher during night hours than during day in 1996 and 1997. The data were more variable in spring than in summer. The authors also observed that diel passage through the sluiceway at the first powerhouse varied from turbine passage. During both the spring and summer smolt migrations, the majority of passage through the sluiceway occurred during the early morning hours with a peak at approximately 0300. Passage was reduced during daytime hours, with a secondary peak shortly after sunset.

Second Powerhouse

The patterns of diel variation in fish passage rates during the spring migration, seen at the first powerhouse, do not seem to be as strong or consistent at the second powerhouse. Studies by BioSonics Inc.(1998) showed little diel variation at Unit 11A (both guided and nonguided) with no peak at dusk. Spring studies by Ploskey et al. (1998) showed a nighttime peak for a couple of treatment days, but the majority of days had highly variable data, with no consistent pattern.

During summer migration studies by BioSonics Inc. (1998), subyearling chinook salmon exhibited a minor diel variation in Unit 11A with highest fish passage between 2100 and 2200. However, Ploskey et al. (1998) observed a pronounced nighttime peak from 2200 to 2300 during summer smolt passage through the turbines at the second powerhouse.

Similar to the Bonneville First Powerhouse sluiceway, spring time fish passage through the sluice chute at Bonneville Second Powerhouse occurred during early daytime, between 0600 and 1300 (BioSonics Inc. 1998). A second smaller increase in passage rates was observed between 1800 and 2100. During the summer migration, the peak passage rates through the sluice chute occurred between 0600 and 1800. The hours of lowest passage through the sluice chute were from 2100 to 2200, coinciding with the hours of highest fish passage of guided fish into Unit 11A

Spillway

A limited amount of hydroacoustic data is available pertaining to diel timing of juvenile salmonids through the spillway. BioSonics Inc. (1998) found that fish passage rates were higher during nighttime at the spillway in the spring. These results were not adjusted for changes in spill levels; however, because of high river flows, spillway discharges showed little variation during the spring. During the summer, fish passage rates were also highest at night at the spillway; however, this was in part due to spillway operations, when Spillbay 5 (with transducer) was typically closed between 0500 to 2200.

In 1999, Plumb et al. (2001) found that regardless of release site, more fish were first detected at the spillway (37%) than at Bonneville First (31%) or Second Powerhouse (29%). Median forebay residence times for hatchery steelhead were 5.6, 3.9, and 0.3 h for the two powerhouses and spillway, respectively. Corresponding times for yearling chinook salmon were 1.0, 0.2, and less than 0.1 h. Additionally, fish from all releases passed the dam throughout the diel period, with slightly higher numbers during night passage (2000-0659).

During the low flow year of 2001, Evans et al. (2001a) found that passage rates were highest for yearling chinook salmon during the day at the spillway and at Bonneville First Powerhouse, but nighttime passage was the highest at Bonneville Second Powerhouse. Overall diel passage was generally flat. A higher proportion of the total daily passage occurring during the day (0500-2059), but hourly passage was highest at night, with peak hourly passage at sunset (2100). Also, the median residence times in the forebays of Bonneville Dam ranged from 8 min to 9.7 h depending forebay area. In a similar study on subyearling chinook salmon, Evans et al. (2001b) found that median forebay residence time was shortest for the second powerhouse (0.7 h) compared to 2.4 h at the first powerhouse and 1.5 h at the spillway. Diel passage was very similar to that reported above for yearling chinook salmon.

Diel Passage Conclusions

1. Passage timing for each route varies with dam configuration, flow volume through the route of passage, species, and life history type. Most studies were not designed to evaluate 24-h passage behaviors for each species and life history type, making it difficult to precisely describe passage timing for each dam under varying conditions.

2. In general, juvenile migrants that arrive during daytime tend to not pass through powerhouse routes (turbines and bypass) on arrival, but will readily pass through surface-oriented outlets and daytime spill if provided.

3. In general, for juvenile migrants that arrive at night, passage is more equally distributed amongst available routes.

JUVENILE SALMON PASSAGE THROUGH SURFACE BYPASS SYSTEMS AND SLUICEWAYS

Juvenile yearling salmon generally migrate in the upper portion of the water column and approach FCRPS dams near the surface (Dauble et al. 1999, Johnson et al. 2000). However, most turbine intakes and all spill gate sill elevations are greater than 40 ft below forebay water surfaces. Thus, juvenile migrants have to follow flow lines downward into turbine and spill intakes, a behavior that is counter to their normal, surface orientation. Also, juveniles can accumulate in the immediate forebay during the day at sites where spill is limited or nonexistent, and pass the dam at night. Delay of juvenile migrants in forebays may increase losses to predation (Raymond and Sims, 1980).

Many of the older FCRPS dams were constructed with surface-oriented ice and trash sluiceways to pass ice and debris from the forebay to the tailrace. These include (year completed) Ice Harbor Dam (1962), The Dalles Dam (1957), and Bonneville Dam First Powerhouse (1938). The sluiceways include adjustable weir gates above turbine intakes which pass water from the forebay into a longitudinal channel around the dam to the tailrace. In addition, the Bonneville Dam Second Powerhouse was constructed in 1983 with a surface outlet located in one corner of the powerhouse to pass ice and debris to the tailrace.

The Ice Harbor Dam sluiceway was evaluated in 1995 prior to installation of a juvenile bypass system in the sluiceway channel. Combinations of wide, surface-overflow entrances (20 ft wide, 6 ft deep, and 7.5 ft s^{-1} entrance velocity) and deeper, slotted entrances (up to 6 ft wide, 40 ft deep, and up to 4 ft s^{-1} entrance velocity) were studied. The wide, surface-overflow entrances had the highest passage rates based on hydroacoustics (Biosonics 1996b) and radiotelemetry, where a total of 57% of the radio-tagged chinook salmon used sluice gate 2B which was a surface skimming flow (Swan et al. 1996).

The Dalles Dam sluiceway is located along the entire length of the 22-turbine-unit powerhouse, which is oriented parallel to the river channel centerline. Surface flow passes through weir-type chain gates into a channel that has a hydraulic capacity of 5,000 cfs. Typically, three gates above turbine unit 1 at the west end of the powerhouse are opened to pass 3,200 cfs through the sluiceway. During periods of no spill, sluiceway passage was estimated at 40 to 55% (Giorgi and Stevenson 1995). However, sluiceway passage is reduced during periods of spill. For example, in 2000, estimated sluiceway passage was 6 and 7% during the spring and summer, respectively, during 40% spill (Moursand et al. 2001c).

The Bonneville Dam First Powerhouse is perpendicular to the river channel centerline. Estimates of sluiceway efficiency have ranged from 83% for steelhead (Willis and Uremovich 1981) to 13% for subyearling chinook salmon (Krcma et al. 1982), and vary highly by species, flow, time of day, estimation method, forebay elevation, the number of turbines operating, and which sluiceway weirs are open. Although the capacity of the northern most sluice gates was reduced in the early 1980s by installation of a juvenile fish bypass system, total sluiceway capacity was not reduced, and remains at approximately 1,000 cfs. In 2002, estimated sluiceway passage was 33% (95% CI, 32-34%) for spring and 29% (95% CI, 28-30%) for summer with gates 7A and 10C operating, under conditions of 24-h spill and the Bonneville Dam Second Powerhouse being operated as the priority powerhouse. Sluiceway passage during both spring and summer was higher during day than night (Ploskey et al. 2003).

Sluiceway survival is a function of direct mortality that occurs during passage through the sluiceway and plunge into the immediate tailrace, and delayed mortality that occurs downstream. Estimated survival through sluiceways varies with life-history type, time of day, and spill conditions. For example, estimated survival through The Dalles Dam sluiceway in 1998 was 0.960 (95% CI, 0.874-1.054) for coho salmon under 30% spill during the daytime, while estimated survival of subyearling chinook salmon was 0.889 (95% CI, 0.806-0.980) during 30% daytime spill. In 2000, estimated survival of yearling chinook salmon was 0.945 (95% CI, 0.895-0.998) during daytime and 0.940 (95% CI, 0.889-0.995) at night during 40% spill. Estimated survival of subyearling chinook salmon was 0.955 (95% CI, 0.849-1.074) during daytime and 0.972 (95% CI, 0.864-1.094) at night during 40% spill (Absolon et al. 2002).

These sluiceway evaluations suggest that downstream migrants use non-turbine, surface-oriented passage routes, especially during daytime and periods of non-spill. Relatively high passage rates resulted in the sluiceways being highly effective, given their low hydraulic capacity relative to total river discharge. However, their low hydraulic capacity also limited further increases in the percentage of fish that could be passed through these routes.

Wells Dam on the upper Columbia River (completed 1967) is configured differently than all other run-of-the-river dams on the Snake and Columbia Rivers. Powerhouse turbine intake ceilings are 70 ft deep, with 11 spillway gates located over and between the ten turbines. Each of the five turbine pairs has one surface bypass entrance 16 ft wide by 73 ft deep. The surface bypass entrance velocity is approximately 2 fts^{-1}, and each surface bypass slot passes up to 2,200 cfs. Bypassed fish and flow pass through the surface entrances into an afterbay between the entrance and the spill gate, and are discharged to tailwater through the spillway gates, which control bypass entrance flow and velocity. Surface bypass flow is 5 to 7% of the hydraulic capacity of each pair of turbines (Johnson 1996). Evaluations of a surface bypass system at Wells Dam demonstrated that surface-oriented fish will pass in large numbers through the surface route with a relatively small flow. Surface bypass entrance efficiency (ratio of fish passing into the bypass relative to fish passing both the bypass entrance and turbine pair) is approximately 90% (Johnson et al. 1992), and ranges from 84.3 to 95.0% for spring migrants and 76.5 to 97.0% for summer migrants (Skalski et al. 1996).

Prototype Surface Bypass Systems

Based on the successful performance of the Wells Dam surface bypass system, prototype surface bypass systems have been tested at a number of locations in the Pacific Northwest to determine whether fish behavior principles observed at Wells Dam could be applied to dams with appreciably different and more typical powerhouse and spillway configurations, but with similar fish passage performance results. Evaluations of prototype surface bypass systems commenced in 1995 at Wanapum and Rocky Reach Dams, at Lower Granite Dam in 1996, at the Bonneville Dam Second Powerhouse in 1997, and the Bonneville Dam First Powerhouse in 1998. Prior to the 1998 evaluation, the Lower Granite surface bypass collector prototype was deepened to simulate the Wells Dam intake, and a behavioral guidance device was installed. A J-block occlusion device was installed at the west turbine units of The Dalles Dam in 2001, and a removable spillway weir was installed at Lower Granite Dam in 2002.

In 1995, a 55-ft deep prototype surface collector was installed upstream of turbine units 7-10 at Wanapum Dam. A single 16 ft wide by 50 ft deep slot entrance with a hydraulic capacity of 1,400 cfs was located directly above turbine unit 8. The structure occluded the upper portion of the turbine intakes. Due to poor performance of the slot entrance, reduced turbine entrainment associated with the turbine intake occlusions, and increased entrainment through turbines without intake occlusions, the prototype collector was extended in 1996 to also occlude turbine units 4-6. Additional collector entrances were not added. Mean collector efficiency (percent of fish entering the prototype collector relative to the total passing into the collector plus the number passing into reference units) was 30% in 1995 relative to turbine unit 8, and averaged 12% relative to turbine units 7-10. Horizontal distribution across the powerhouse was skewed toward turbine units not covered by the occlusion device, when compared to distribution in years before the prototype collector was installed (Ransom et al. 1996). Further, spillway efficiency during surface bypass prototype testing was higher (43%) than in previous years (30%; Kumagai et al. 1996). This suggests the prototype surface collector may have reduced entrainment at the occluded units, and fish passed over the spillway, increasing spillway effectiveness. The prototype collector was again extended in 1997 to occlude turbine units 1-3, and mean collector efficiency relative to turbine unit 8 averaged 15%, and was 0.9% relative to the entire 10-unit powerhouse during the spring (Kumagai et al. 1997).

Rocky Reach Dam has an eleven-unit powerhouse oriented parallel to the river channel centerline, similar to The Dalles Dam. Juvenile salmon accumulate at the downstream half of the powerhouse between the powerhouse and a non-overflow wall connecting the powerhouse to the west shoreline (Dauble et al. 1999). Evaluations of various prototype surface collection configurations occurred from 1995 through 2002. In 2003, a permanent surface bypass facility was constructed consisting of a single, 40 ft wide by 50 ft deep entrance located immediately downstream from turbine unit 1 with a hydraulic capacity of 6,000 cfs. Most of this flow is screened and pumped back to the forebay. Fish from the surface collector and screened juvenile fish bypass system in turbine units 1 and 2 are routed across the downstream face of the powerhouse and spillway to monitoring facilities and an outfall located on the east shore. Estimated fish passage efficiency (proportion of fish passing through non-turbine routes including the surface bypass, intake screen bypass, and spillway) was 66, 68, 31, and 42% for yearling chinook salmon, steelhead, sockeye salmon, and subyearling chinook salmon (Mosey 2003).

Lower Granite Dam has a six-unit powerhouse located immediately to the south of eight spill bays. In 1996, a prototype surface bypass collector was installed immediately upstream from turbine units 4-6, consisting of a 20 ft wide by 60 ft deep channel, the bottom of which was at the same elevation as the turbine intake ceiling. Attraction flow passed through various entrance configurations and was conveyed through a longitudinal channel to an adjacent spillbay. Maximum discharge through the collector was 3,500 cfs, and flow control was provided by the spill bay gate.

From 1996 through 2000, 11 different entrance configurations were tested at the Lower Granite Dam surface bypass collector to evaluate the effects of entrance characteristics such as discharge, shape, orientation, area, velocity, and change in rate of accelerations (Anglea et al. 2002). In 1998, based on hydraulic model studies, a 15-ft extension was installed on turbine units 4-6 to emulate hydraulic conditions observed at Wells Dam. The upper 17% of the turbine intakes was occluded which decreased the magnitude of downward velocities at mid-depths in the forebay upstream of the collector (Johnson et al. In review). Also in 1998, a 330 m long floating curtain was installed to affect the horizontal distribution of juvenile salmon in the forebay and divert them from turbine units 1-3 to units 4-6 and the collector. The height of the curtain varied from 17 to 24 m. Hydroacoustic evaluations were used to evaluate passage for the general population and compare collector to non-collector passage routes. Radiotelemetry was used to evaluate the responses of yearling chinook salmon, hatchery and wild steelhead, and subyearling chinook salmon to the various configurations tested.

In 1997, 12% of fish passing the dam did so through the collector, based on hydroacoustics (Johnson et al. 1998). Similarly, from 6 to 10% of radio-tagged hatchery and wild steelhead and hatchery spring chinook passed through the collector as compared to the total passing the dam, and from 43 to 65% of the radio-tagged fish that passed within 6 m of the entrances passed through the collector (Adams et al. 1998c). In 1998, by installation of the forebay curtain and collector modifications, the objective was to determine whether horizontal and vertical distribution could be modified to increase the number of fish near the entrances and passing through the collector. More fish were observed in front of the collector and fewer fish were entrained into turbine units 4-6. Passage efficiency was from 14 to 34% depending on species, and from 14 to 51% of fish within 10 m of the entrances passed through the collector. A total of 92, 61, and 67% of radio-tagged hatchery steelhead, hatchery spring chinook salmon, and wild steelhead that approached turbine units 1-3 stayed to the north of the forebay curtain (Adams and Rondorf 2001). Additional research was conducted in 1999 and 2000 with similar results.

Research conducted from 1966 to 2000 showed that surface flow bypass is a valid concept for Lower Granite Dam (Johnson et al. In review). Both spillway efficiency and passage of fish through non-turbine routes increased. For example, performance of the surface bypass collector increased spillway fish passage efficiency from 30 to 57% in 1998 (Johnson et al. 1999). It also improved passage through non-turbine routes at the powerhouse. In 1998, an estimated 83% of the downstream migrants were guided into the bypass system relative to total powerhouse passage, and this increased to 90% when passage through the surface bypass collector was included. Also, concentrating inflow in a single surface entrance produced the optimum configuration. Finally, surface bypass efficiency alone was not high enough for it to be a stand-alone bypass system, but when used in combination with spill and the juvenile bypass system, passage past the dam through non-turbine routes exceeded 90% with more than half of these fish using the collector (Johnson et al. In review).

The Bonneville Dam Second Powerhouse sluice chute is located immediately south of turbine unit 11, the southern-most of eight turbines at the powerhouse. The entrance is 15 ft wide by 20 ft deep and discharges approximately 3,000 cfs. Strong lateral flows toward the north and south ends of the powerhouse concentrate juvenile fish at these locations (Monk et al. 1999a). In 1998, with the six southern-most turbine intake extensions removed (over turbine units 11-14), 52% of the radio-tagged steelhead and

36% of the radio-tagged yearling chinook salmon approaching the powerhouse passed through the sluice chute, compared to 21% of the tagged steelhead and 14% of the tagged yearling chinook salmon detected in the juvenile bypass system. When the chute was closed, 50% of the steelhead and 30% of the yearling chinook salmon were detected in the bypass system (Hensleigh et al. 1998). The combined efficiency of the sluice chute and juvenile bypass system relative to passage through the chute and turbine units 11-13 was 90% during both spring and summer periods, based on hydroacoustics. When the chute was closed, guidance into the juvenile fish bypass system was 55 and 30% of the total fish passing turbine units 11-13 during the spring and summer, respectively. For the sluice chute alone, chute efficiency (proportion of fish passing the chute relative to passage through turbine units 11-13 and the chute) was 83 and 81% in spring and summer, respectively. The effectiveness of the sluice chute was high; about five times more fish passed the chute than would be expected based on the proportion of water passing the chute (Ploskey et al. 1999).

The Bonneville Dam First Powerhouse consists of 10 turbines and is separated from the spillway by Bradford Island. A prototype surface collector in front of turbine units 3-6 was installed in 1998 and evaluated to determine whether occluding the upper intake and passing high flows through a deep-slot entrance would successfully attract fish. The bottom of the collector was from 36 to 42 ft below the water surface and flow through the entrances was routed into the turbine intake. Both 5- and 20-ft wide entrances were tested, which passed approximately 1,000 and 3,000 cfs, respectively.

Ploskey et al. (1999) estimated that collector entrance efficiency was approximately 90% for both spring and summer migrants for both entrance configurations, based on hydroacoustics targets that passed into and under the prototype collector. However, while 45% of the radio-tagged steelhead and 40% of the radio-tagged yearling chinook salmon detected upstream from the first powerhouse passed near the prototype collector, 67% of these fish did not enter the collector and instead moved south along the face of the structure, and initially held upstream from turbine units 1 and 2 (Hensleigh et al. 1998).

In 2000, the prototype collector was expanded southward through turbine unit 1 to attempt to collect fish moving laterally (as observed in 1998). Estimated collection efficiency (the number entering the collector relative to the total number passing turbine units 1-6) was 83, 78, and 81% for radio-tagged steelhead, yearling spring chinook salmon, and subyearling spring chinook salmon, respectively. Also, 71 and 59% of the radio-tagged steelhead and yearling chinook salmon approached more than one entrance before passing (Evans et al. 2001a). Multi-beam hydroacoustic evaluations conducted to evaluate behavior in front of the collector found extensive milling of fish within 5 m of the entrances (Johnson et al. 2001).

In 2002, the upper 45 ft of the turbine intake trashracks at The Dalles Dam were occluded to increase sluiceway passage efficiency. This was based on reduced entrainment of juvenile salmon into turbines at Wanapum and Lower Granite Dams after installation of structures that occluded the upper portion of the turbine intakes at these dams, and strong lateral flows toward the west end of the powerhouse and spillway, and the open sluiceway entrances at the west end of the powerhouse at The Dalles Dam. The "J" shaped occlusions were installed in intakes of two fish attraction flow and four main turbine units at the west end of the powerhouse. The long stem of the "J" blocked the intake, and the nearly horizontal leg extended 20 ft upstream and then upwards 10 ft at a 90-degree angle. In 2002, there was no difference in turbine entrainment with the occlusions installed or removed during the spring; however, turbine entrainment was higher during periods with the "J" device installed during the summer (Johnson et al. 2003). Turbine priorities were different in 2002 compared to previous years, which resulted every other turbine unit being operated. In 2002, spill passage efficiency dropped to 45 and 38% during the spring and summer, respectively, which was lower than in previous years and may have been affected by the turbine operations that year. For example, in 2000, spill efficiency was 86 and 74% during the spring and summer, respectively (Moursand et al. 2001c). The turbine operations in 2002 may have influenced turbine entrainment and the performance of the occlusions.

In 2001, a removable spillway weir (R.W.) was installed in the southern-most spillbay at Lower Granite Dam. The R.W. is nearly 50 ft wide and has a 19.5 ft long ramp extending upstream. The approach ramp was incorporated into the design based on Haro et al. (1998), where juvenile Atlantic salmon passed more readily over weirs with gradual velocity increases upstream of the crest as compared to sharp-crested weirs. The R.W. weir crest is from 11 to 15 ft below normal water surface elevations and transitions to the existing ogee of the spillbay. Discharge through the weir is 7,000 cfs at minimum operating pool. The weir is designed to rotate 90 degrees in the upstream direction to a lowered position to not reduce spill capacity during high river discharge.

In November 2001, a preliminary study using balloon-tagged hatchery yearling chinook salmon found no significant differences in survival or injury rates between fish released into the R.W. and into an adjacent spillbay that was partially-opened and outfitted with a deflector. Estimated 1- and 48-h survival probabilities for fish passing through the R.W. were 0.992 (90% CI, 0.983-1.000) and 0.981 (90% CI, 0.966-0.995), respectively. Estimated 1- and 48-h survival probabilities for fish passing through the adjacent spillbay were 1.00 and 1.00, respectively, and the survival probabilities between the two routes were not significantly different (*P* >0.05; Normandeau Associates et al. 2002).

In 2002, the R.W. was evaluated by comparing bypass efficiency (ratio of fish passing the R.W. and adjacent training spill to total passage) to spill passage efficiency (ratio of fish passing spillway to total passage). During the R.W. tests, spill of 7,000 cfs was provided through the R.W., spill through adjacent bays was provided to establish satisfactory tailrace egress conditions, and total spill was 15,000 cfs and 23,000 cfs. During spill-to-the gas-cap tests, spill of approximately 45,000 cfs was provided though seven spillbays 12 h at night. Surface bypass collector components remained in turbine units 4-6, the floating curtain was attached to the southern end of the surface collector, and surface collector components north of the powerhouse that had routed collector flow to the spillway were removed.

In 2002, the bypass efficiency of the R.W. (the ratio of fish passing the R.W. to fish passing through all routes) was 56, 62, and 61% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. The bypass efficiency of the R.W. and the adjacent training spill was 78, 73, and 78% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. In comparison, spill passage efficiency during the spill-to-gas-cap tests was 62, 66, and 54% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. While training spill adjacent to the R.W. was greater than 50,000 cfs for part of the evaluation period because of high river flow, the combined bypass efficiency of the R.W. and training spill during these periods was similar to the combined bypass efficiency observed when adjacent training spill was 8,000 and 16,000 cfs (Plumb et al. 2003a).

In 2003, the surface bypass collector was removed which eliminated the intake occlusions in turbine units 4-6, and the floating curtain in the forebay was stored well upstream from the dam and had no influence on fish behavior and distributions. Flow through the R.W. was again 7,000 cfs and training spill through adjacent spillbays totaled 12,000 cfs. Due to a more stable hydrograph, flow through spillbays adjacent to the R.W. was more consistent than in 2002. The bypass efficiency of the R.W. (the ratio of fish passing the R.W. to fish passing through all routes) was 58, 69, and 67% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. The bypass efficiency of the R.W. and the adjacent training spill was 66, 74, and 71% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. In comparison, spill passage efficiency during the spill-to-gas-cap tests was 52, 59, and 54% for radio-tagged hatchery yearling chinook salmon, hatchery steelhead, and wild steelhead, respectively. Passage through the R.W. was greatest during daylight hours. Median forebay passage times during R.W. tests were 1.92, 1.72, and 2.28 h for radio-tagged hatchery and wild steelhead, and hatchery chinook salmon, respectively. For these same test groups, median passage times during spill-to-the-gas-cap tests were 7.37, 4.64, and 4.98 h, respectively. The estimated relative survival of radio-tagged hatchery yearling chinook salmon passing through the R.W. was 0.980 (95% CI, 0.957-1.03), compared to estimated survival through the spillway under spill-to-the-gas-cap spill of 0.931 (95% CI, 0.871-0.991). There were no significant differences between the treatments (P = 0.1135; Plumb et al. 2003b).

Locations of acoustically tagged hatchery yearling chinook salmon and hatchery and wild steelhead in three dimensions from 2002 and 2003 were integrated with numerical model depictions of hydraulic flow fields for Lower Granite Dam operations during time of passage of test fish. The goal was to understand fish behavioral responses to hydraulic conditions in the forebay that would help improve the performance of future surface bypass configurations. Tagged fish generally stayed more than 15 ft away from the upstream face of the 80 ft deep forebay curtain, and tagged fish in the upper 15 ft of the water column generally stayed upstream of the 4 ft deep trash shear boom. The common hydraulic condition in which fish appeared to respond is called strain. Another objective of this integration was to determine the percentage of tagged fish that passed through the R.W. having approached form various distances upstream from the R.W. This was based on observations of fish delaying just upstream from deep-slot surface bypass entrances at the Bonneville Dam First Powerhouse, Lower Granite Dam, and Wanapum Dam. In 2002, 80% of the tagged wild steelhead that passed within 70 m, 80% of tagged hatchery steelhead that passed within 40 m, and 80% of the tagged hatchery chinook salmon that passed within 20 m of the R.W. passed through the surface weir (Cash et al. 2003).

Discussion

Surface bypass performance is a function of forebay collection, safe passage through the surface bypass entrance conveyance, and safe and rapid tailrace egress. Testing of prototype surface bypass systems during the past decade focused primarily on measuring how many fish were guided out of the forebay and into the bypass, an issue considered the greatest challenge at most sites. Results indicate that bypass guidance efficiency varied with location, and where successful, no single feature or operation was responsible. Rather, a combination of factors appear to influence both forebay hydraulic conditions and related fish behavioral responses. These include

1. selection of a location where fish accumulate (naturally or artificially through guidance structures),
2. surface-oriented entrance(s) with unimpeded surface drawdown, and open, natural lighting beyond the weir crest,
3. gradual, increasing velocity as flow approaches the weir crest,
4. use of a floating trash boom or guidance curtain may improve forebay collection performance,
5. larger bypass flows increase passage efficiency, but do not overcome other deficiencies or compromises, and
6. increased discharge through turbines and the spillway reduces passage through surface bypass systems.

Deep-slot entrances at Wells Dam were highly effective, passing approximately 90% of yearling and subyearling migrants. Also, surface-oriented entrances with weir-type flow have historically passed a large number of fish with small quantities of flow. Prototype surface bypass facilities that have proven successful are the Bonneville Dam Second Powerhouse sluice chute and the Lower Granite Dam R.W. The weir entrance appears to collect surface-oriented fish, but also some deeper fish move vertically to pass into the entrance (Cash et al. 2003). Furthermore, there are no signs of fish holding for extended periods upstream of the R.W. as compared to observations in front of deep-slot entrances. These observations suggest that volitional passage of juvenile salmonids is more attainable over weirs than through deep-slot entrances. However, fish respond differently to hydraulic conditions in the weir entrance and approach to the weir, and favor gradual rather than sharp velocity increases (Haro et al. 1998).

In contrast, data from most sites suggest that deep-slot entrances do not perform as well as surface oriented weirs. Fish appeared to delay and avoid entering multiple, deep-slot entrances with lower velocities from 1 to 4 fts^{-1} at Lower Granite Dam and the Bonneville Dam First Powerhouse, and many radio-tagged fish moved back upstream. Multi-beam hydroacoustic studies also identified fish holding immediately upstream from the deep-slot entrances, suggesting a lack of volitional movement into this type of entrance. Also, many radio-tagged fish moved laterally rather than directly into, or under, the prototype surface collector entrances at turbine units 3-6 at Bonneville Dam First Powerhouse in 1998. Fish behavioral investigations have not been conducted upstream of the surface bypass entrances at Wells Dam, and therefore it is not known whether delay is associated with this type of deep-slot entrance.

Surface bypass system performance is related to the proportion of flow through the system. Johnson et al. (In review) suggest that surface bypass flow needs to be greater than 7% of project flow to establish a large enough flow net in the forebay to be effective, based on studies at Wells Dam. However, the configuration of the Wells Dam surface bypass system is unlike any other dam. Therefore, this criterion should be used as a guide and adjusted to meet unique conditions associated with each potential surface bypass location. Performance also appears related to total project flows. For example, at Lower Granite Dam when average project discharge was 85,000 cfs, approximately 60% of the tagged juvenile fish passed through the R.W. or spillway, and this dropped to 40% when average project discharge was 110,000 cfs.

While the forebay guidance curtain at Lower Granite Dam appeared to influence horizontal distribution of fish at the powerhouse in 1998, the potential benefit appears dependent on total project discharge and project operations, and it remains to be determined as to when and under what conditions guidance curtains perform best. For example, the R.W. performed better with the guidance curtain removed in 2003 than when deployed in 2002, and both shallow (4 ft deep trash shear boom) and deep (80 ft deep curtain) devices have been shown to alter fish behavior.

During the mid and late 1990s, surface bypass designs and implementation decisions were made based on the best possible synthesis of biological and hydraulic observations. Hydraulic observations were largely from physical hydraulic models and fish behavioral information was primarily from hydroacoustic and radiotelemetry studies. Radiotelemetry provided an indication of fish location in two dimensions and to the nearest 10 m. However, the emphasis was placed on developing the ability to track fish in three dimensions at finer spatial scales to gain an improved understanding of fish behavior. Additionally, computational fluid dynamics models (with visualization software) were developed that allowed coarse and fine grid observation of forebay hydraulic conditions. Integrating acoustic tag and hydraulic model outputs was necessary to identify fish behaviors and optimize surface bypass system designs and performance.

Thus, three-dimensional evaluations at Lower Granite Dam using acoustically-tagged fish were conducted to assess fish movement under various operations and forebay hydraulic conditions and identify any previously undetected fish responses to forebay hydraulic conditions (Cash et al. 2003). Fish behaviors near both the guidance curtain and trash shear boom were noted in 2002, where fish appeared to avoid zones immediately upstream of both the 80 ft- deep guidance curtain (first observed in 1998) and the 4 ft- deep trash shear boom. Investigation of hydraulic conditions in the zones immediately upstream of both devices suggests these are areas where strain, as defined as the derivative of the vertical velocity component, can be detected.

The integration of hydraulic flow fields and biological data discussed above allows fish behavior in response to existing configurations under certain operations to be reviewed. Nestler and Goodwin (in prep.) have developed a fish behavior model to analyze potential, future configurations and operations. Preliminary analyses suggest the model can be used at larger scales, such as designing the appropriate length, depth, and location of forebay guidance curtains. The methodology is still developing and currently does not appear appropriate for fine-scale determinations such as entrance configuration or discharge.

A successful surface bypass system also requires safe passage through the structure, at the point where the surface bypass discharge jet enters the tailrace, and during egress through the tailrace. Routing a large surface bypass discharge directly to the tailrace results in high impact velocities and potential losses associated with mechanical effects (shear, strike, abrasion) or predation. Northern pikeminnow (*Ptychocheilus oregonensis*) and gulls (*Larus* spp.) may accumulate at sluiceway or bypass outfalls and shallow areas directly downstream (Hansel et al. 1993, Ward et al. 1995, Jones et al. 1997, and Snelling and Mattson 1998). Also, Northern pikeminnow can respond quickly in tailraces to changes in project operations (Faler et al. 1988), emphasizing the need to design good egress conditions in the immediate tailrace. Surface bypass system outfalls are generally located where bypass flow quickly passes downstream to minimize fish exposure to eddies and stagnation zones. For example, radio-tagged spring chinook migrated past a transect 1.2 km downstream of Lower Granite Dam in 19 to 23 min when passage was through the R.W. with training spill, compared to some fish taking up to five times that long when passing during normal spill conditions (Plumb et al. 2004).

Development of surface bypass systems at collector dams required evaluating the feasibility of dewatering large flow volumes if surface bypassed fish were to be transported. Mechanical screening systems of unprecedented size would be required to achieve uniform through-screen velocity distributions, and reliable debris cleaning and removal capability would have to be included in the design. Therefore, a study of high-flow dewatering and high-flow outfall alternatives was conducted for the Bonneville Dam First Powerhouse (ENSR et al. 1998). Based on the options evaluated, NOAA Fisheries and other salmon management agencies recommended use of high-flow outfalls to convey flow to tailraces, and that further high-flow dewatering investigations be curtailed. However, the high-flow outfall alternative required confirmation that discharges greater than 1,000 cfs and impact velocities greater than 25 fts^{-1} (NMFS criteria) would not result in elevated injury rates. Based on laboratory studies, impact velocities up to 52 fts^{-1} at the point of jet entry produced safe conditions for juvenile salmon. Similarly, field studies at the Bonneville Dam Second Powerhouse sluice chute indicated no mortality and injury rates of 2% associated with tailrace impact velocities of 48 fts^{-1} (Pacific Northwest National Laboratory et al. 2001). These data suggest that surface bypass system outfalls with discharges greater than 1,000 cfs and impact velocities up to 50 fts^{-1} can be safely designed.

Passage through Surface Bypass Systems Conclusions

1. Results from studies of the Lower Granite Dam removable spillway weir and Wells Dam deep-slot surface bypass systems demonstrate that surface bypass is a viable concept that can produce high rates of non-turbine fish passage with a relatively small percentage of project discharge. However, poor or marginal results from other studies indicate that satisfactory results are not always achieved with surface bypass systems, and site conditions may limit performance at some locations. Also, it can take several years of testing various configurations under different flow regimes to determine the best design and project operations.

2. Optimum surface bypass performance is attained when the entrance(s) are at a location(s) known to attract large numbers of fish. Weir entrances have proven more successful at passing juvenile salmon and steelhead migrants than deep-slot entrances. Fish appear to pass weir-type entrances most readily if flow velocity into and through the weir increases gradually. Discharge capacity should be sufficient to create a strong upstream velocity flow-field, but high discharge alone will not overcome a marginal entrance location.

3. Surface bypass systems operated 24 h per day reduce forebay residence times of juvenile salmon and potential exposure to predators relative to the existing program of 12-h spill at night. At Lower Granite Dam, forebay residence times of radio-tagged juvenile salmon were from two to four times lower with a removable spillway weir operating compared to spill-to-gas-cap operations, potentially reducing mortality due to predation in the forebay.

4. A surface bypass entrance by itself may not be enough to achieve high rates of dam passage through non-turbine routes. Additional passage facilities, such as a floating forebay curtain or upper turbine intake occlusion device, have been successful in guiding fish.

5. Successful surface bypass designs need to address guidance into the entrance, passage through the collector, discharge into the tailrace, and egress through the immediate tailrace to achieve passage performance goals of high passage efficiency and survival. Recent data indicate that for discharges greater than 1,000 cfs impact velocities up to 50 fts^{-1} are safe for juvenile salmon.

6. Tracking of fish in three dimensions through use of acoustically-tagged fish and integration of these data with hydraulic conditions from computational fluid dynamics modeling allows for a comprehensive assessment of fish behavior upstream of large hydroelectric dams, and may increase the potential for achieving fish passage objectives.

JUVENILE SALMON PASSAGE THROUGH TURBINES

Early studies of juvenile salmon passage at FCRPS dams reported high levels of mortality (8-19%) for fish passing through turbines (Holmes 1952, Schoeneman et al. 1961, Long et al. 1968). As a result, salmon managers have focused on providing safer, non-turbine passage routes for juvenile fish to improve survival. Nevertheless, substantial numbers of juvenile fish continue to pass through turbines, and reducing turbine-related mortality remains an important factor in improving the survival of fish migrating through the hydropower system.

Salmon managers need to know current levels of mortality for different species, runs, and life-history stages that NOAA Fisheries will use to evaluate hydropower system effects on listed stocks. Also, it is important to inform managers about whether survival through turbines can be increased by modifying current turbine operations, and whether new turbine designs hold promise for improving physical conditions within the turbine environment. In this section we discuss the methods available to estimate turbine passage survival and injury, provide estimates of fish survival through turbines made under various operations, and results from studies conducted under Corps and DOE programs to improve turbine designs and operations for fish passage.

Methods

Turbine Survival Estimates based on Juvenile vs. Adult Returns

Early studies of dam passage survival were based on adult returns to hatcheries and recaptures in commercial fisheries. Holmes (1952) conducted releases of juvenile fish at Bonneville Dam from 1939 to 1945 and adult recoveries from 1940 to 1950 to test for differences in survival between spillway and turbine passage routes. He found a somewhat greater loss of fingerling chinook salmon associated with turbine passage, and by assigning varying weights to individual observations, estimated that mortality was from 0.11 to 0.15 through the turbines and spillway mortality was from 0.03 to 0.04. However, the data were highly variable and he concluded that the observed differences between the turbines and spillway could also have been due to “chance variation in sampling where no real differences existed.”

Schoeneman et al. (1961) used inclined plane traps at various locations from 20 to 50 miles downstream from McNary Dam to recapture tagged juveniles and evaluate mortality. Their results were similar to Holmes’, where estimated spillway mortality was

0.02 (95% CI, 0-0.04). Estimated turbine mortality was 0.13 at 80% wicket gate opening and 0.08 at 75% of gate opening. Overall, based on studies conducted at both McNary Dam and Big Cliff on the Santiam River, estimated mortality through turbines was 0.11 (95% CI, 0.09-0.13).

From 1987 to 1992, NOAA Fisheries released 1.5 to 2.2 million differentially marked upriver bright and tule stock juvenile fall chinook salmon each year through various passage routes at Bonneville Dam to estimate short-term survival based on recovery of test fish in the estuary, and long-term survival based on salmon caught in fisheries and adult returns to hatcheries. Sample sizes were established to detect differences of 4 to 5% between release locations based on an estimated adult return rate of 0.5%. However, adult returns of fall chinook salmon to the Columbia River were much lower than expected during the test period. Recoveries of test fish averaged 0.24% for fish released in 1987, and in all other years average recoveries ranged from 0.02 to 0.04% (Gilbreath et al. 1993). These poor return rates increased the range of detectable differences to 12 to 40% and eliminated our ability to make meaningful comparisons among treatments based on adult recovery data. Based on analyses of juvenile recapture data, we found no significant difference between fish released into the turbine and immediate tailrace, but survival of fish released through turbines was approximately 91% of fish released 2.5 km downstream from the second powerhouse.

These studies demonstrate the strengths and weaknesses of studies based on adult versus juvenile recapture data. Adult returns require long sampling periods to obtain results and include additional portions of the salmonid life cycle where biological and environmental effects can result in low or highly variable return rates between years, weakening the power to test for differences between specific treatments. They also require large sample sizes. Studies where adult returns are used as the basis for comparison or adult data are used for trend analysis are presented in the companion Technical Memorandum titled “Effects of the Federal Columbia River Power System on salmon populations.” Studies based on juvenile recaptures can produce statistically valid results based on recaptures the same year, if recapture rates and sample sizes are sufficient. Results of studies based on juvenile recapture data (Schoeneman et al. 1961, Ledgerwood et al. 1990, Absolon et al. 2003) indicate that juvenile recoveries a significant distance downstream from the release site can be used to estimate turbine mortality, since indirect effects from turbine passage expressed downstream of the turbine to the point of recapture are incorporated into the estimate. When treatments through turbines, spillways, bypass systems, and sluiceways are combined into a single test, relative comparisons of survival can be made across the treatments (passage routes) using juvenile recapture data.

Turbine Survival Estimates based on Balloon-Tag, Radiotelemetry, and PIT-tag Methodologies

Mortality associated with turbine passage has two components: direct mortality, which is expressed immediately, and indirect mortality which is expressed downstream of the powerhouse.

Three types of tagging methods are available to investigators of behavior, injury, and survival associated with turbine passage: 1) balloon tags, which are attached externally and inflate so the test fish can be recaptured by netting in the tailrace, 2) telemetry tags (acoustic or radio) that are surgically implanted into the body cavity or inserted in the esophagus, and 3) passive integrated transponder (PIT) tags, that are injected into the body cavity. Both the PIT and radiotelemetry methods require subsequent detection downstream from the treatment area, but do not require subsequent handling once tagged.

Each method has potential biases, such as whether fish selected for tagging represent the general population (species, size, condition, etc.) and whether fish are released such that their redistribution represents the general population. In addition, researchers need to address any bias related to a specific tagging method, such as effects on fish behavior and fate (e.g, vulnerability to predation).

Looking at the relative range in turbine passage survival estimates at a variety of dams based on PIT- and radio-tag methodologies and described below, we note that in general, PIT- and radio-tag based estimates are similar. For example, Absolon et al. (2002) estimated that relative survival of PIT-tagged yearling chinook and coho salmon through turbines at The Dalles Dam was 0.790 and 0.830 in 2000 during the daytime and evening, respectively, and the 24-h survival estimate was 0.810 (95% CI 0.760-0.850). This compares with an estimated yearling chinook salmon survival of 0.869 (95% CI, 0.804-0.933) in 2000, based on radiotelemetry (Counihan et al. 2002). Since the 95% confidence intervals overlap, there is likely no statistical difference between the estimates generated by the two methods.

Comparison of balloon- and radio-tag based data suggests differences may exist between estimates derived by these two methods. At McNary Dam in 2002, NOAA Fisheries used radio-tagged yearling chinook salmon to evaluate fish behavior and survival through two different turbine operations: a discharge of 11,200 cfs, which is at the upper end of the range in turbine efficiency defined as within 1% of peak efficiency, and a discharge of 16,400 cfs, which is outside the 1% range and at the position where the turbine blades are at their maximum angle to the flow. We found no statistically significant differences in fish survival between the two treatments. Estimated relative survival was 0.858 (se = 0.034) and 0.871 (se = 0.016) for the lower discharge and 0.814 (se = 0.037) and 0.856 (se = 0.011) for the higher discharge to two detection locations 46 and 15 km downstream, respectively. These estimates based on radio tags include both direct and indirect effects from passing the turbines to the point of detection downstream. Normandeau Associates et al. (2003c) conducted a concurrent survival study using balloon-tagged yearling chinook salmon and also found no significant differences between the two operating conditions. For fish released during May concurrent with our study, they estimated that turbine survival was 0.930 (90% CI, 0.900-0.970) and 0.946 (90% CI, 0.915-0.981) at the 11,200 cfs and 16,400 operations, respectively, for fish released into the turbine intake and recaptured in the immediate tailrace shortly thereafter. Survival estimates using balloon tags include direct effects from passing the turbines that are expressed immediately within the tailrace prior to recapture or in the first 24 or 48 h of post-recapture holding. Comparison of the two methodologies was facilitated in this case because identical test conditions, time periods within the juvenile salmon migration, and release apparatus and locations were used in the studies, along with similar test fish (yearling chinook salmon collected at McNary Dam). Comparing the two estimates provides insights into potential turbine effects expressed in the reach of river between the immediate tailrace where balloon-tagged fish were recaptured and 46 km downstream based on detections of radio-tagged fish. The balloon tag estimates of survival (Normandeau et al. 2003c) were 6 to 7% higher than our radio-tag estimates for the 11,200 cfs operation and from 9 to 13% higher for the 16,400 cfs operation (Ferguson et al. in prep.).

Bickford and Skalski (2000) analyzed 102 replicate releases of salmonid smolts from 53 survival investigations conducted from 1971 to 1996 at Snake and Columbia River dams and found similar results. Average survival that incorporated both direct and indirect effects from turbine passage was 0.873 through Kaplan turbines. Estimated turbine survival based on 9 balloon tag studies of direct mortality was 0.933.

In contrast, Muir et al. (1996) compared balloon-tag and PIT-tag estimates of survival for yearling chinook salmon released at identical locations within a turbine at Lower Granite Dam. Estimated survival was 0.927 (se = 0.027) using PIT tags and 0.940 (se = 0.023) based on balloon tags. Thus, there was no difference between the estimates derived by the two methods.

Single- and Paired-Release Protocols for Turbine Survival Estimates

Two release protocols have been developed to estimate smolt passage survival. One is the release of a single experimental group of uniquely identified fish that can be detected at downstream sites. Complete capture history permits survival to be estimated based on the assumption that upstream detections have no influence on detection downstream or survival probability. This method requires detections at a minimum of two sites downstream from the treatment area. The single-release protocol allows fish tagged from the general population to redistribute after release and approach the study site in a distribution that represents the general population, and thus the estimates reflect turbine passage survival of the general population. A second protocol is to use paired treatment and control releases, or upstream and downstream releases. The protocol assumes the groups mix and thereafter have equal survival and recapture probabilities. Some form of hose or pipe release must be used for both the treatment and control releases, which forces passage distribution within the turbine to reflect the location of the release mechanism. This is a positive aspect if specific portions of the turbine environment are being evaluated, and can be a negative aspect if the test release is designed to represent the distribution of the general population but the release mechanism is placed in a location that either does not represent the general population or the distribution of the general population is unknown. Test fish released through hoses or pipes are surface acclimated which can cause bias. Abernathy et al. (2001) found that juvenile salmonids acclimated to surface pressure showed little direct mortality, but injury rates increased due to expansion of gas in the swim bladders when fish were acclimated to depth. Also, careful attention should be paid to the design of the release pipe or hose. For example, the exit velocity should match the velocity of the receiving water. Also, test fish must be released into a hose or pipe without injury or stress, otherwise the estimate will be biased. Placement of control releases is another consideration so these releases are not preyed upon differentially by predators. Typically, control fish are released into the turbine boil "front roll" via a hose or in the immediate tailrace via a boat. Passage survival estimates based on radiotelemetry and PIT tags use both protocols, while balloon-tag studies are almost always conducted using the paired-release protocol.

Estimates of Juvenile Fish Survival through Turbines

Turbine passage survival estimates from each study conducted at each dam are provided in Table 9. Survival estimates were categorized as being "direct" if test fish were recaptured immediately (balloon tags or turbine outlet fyke nets), and "total" if test fish were allowed to proceed downstream before detection (PIT tags or radiotelemetry) such that any delayed effects from turbine passage up to the point of detection could be incorporated into the estimate.

Operation of Existing Turbines

All mainstem FCRPS turbines are six bladed, vertical-axis Kaplans, except for Bonneville Dam turbines which have five blades due to lower head (difference between forebay and tailwater elevations; Fig. 6). Curves relating efficiency to unit performance (power output or flow) are developed for any given head.

Turbine efficiency is thought to have a direct effect on fish passage survival. Inefficient turbine operation is a result of a poor blade-to-wicket gate relationship, where efficiency drops due to turbulence and vortex shedding as a result of the rotating machinery (hub and blades) being misaligned with the hydraulic flow field coming off the stationary, but adjustable, wicket gates. The relationship between survival of juvenile fish passing through Kaplan turbines is thought to be positively correlated with unit efficiency, based largely on a visual interpretation of the figures provided by Oligher and Donaldson (1966). However, a statistical evaluation of the same data sets would likely produce a low correlation between unit efficiency and fish survival. Bell et al. (1981) reviewed all the available data and recommended making every effort to operate turbines at peak efficiency during periods of peak fish passage to minimize fish mortality.

NOAA Fisheries recognized the relationship between turbine efficiency and fish survival and adopted this recommendation as part of their FCRPS Biological Opinions (NMFS 1995, 2000). Since 1992, turbines at Corps projects have been operated within 1% of peak unit efficiency during the juvenile migration period (NMFS 1995). The Corps provides the turbine operating points necessary to meet the BiOp requirement in their annual Fish Passage Plan, and any updates are coordinated with Bonneville Power Administration and salmon managers through the Corps Fish Facility Operation and Maintenance Team.

Table 9. Turbine Passage Survival Estimates for Snake and Columbia River Dams. Abbreviations: PIT-Passive Integrated Transponder, B-Balloon, C-Coded wire tag, R-Radio; SHT-steelhead, SYCS-subyearling chinook salmon, YCS-yearling chinook salmon, S-Single release, P-Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Lower Granite Dam									
1988	Giorgi et al. 1988	PIT	P	YCS	Point; turbine intake	Downstream from Unit 3 turbine boil	Normal load response	Not estimated	0.831 (95% CI 0.741-0.922)
1993	Iwamoto et al. 1994	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver off juvenile bypass outfall	Normal load response	Not estimated	0.823 (SE 0.025)
1994	RMC Environmental 1994	B	P	YCS	Point; turbine intake EL 623'	Draft-tube exit	Normal load response	0.946 (90% CI 0.955-0.992) 1 hr survival	Not estimated
1995	Normandeau 1995	B	P	YCS	Point; turbine intake EL 603'	Draft-tube exit	18 kcfs Discharge	0.975 (90% CI 0.955-0.992) 1 hr survival	Not estimated
					Point; turbine intake EL 603'			0.975 (90% CI 0.955-0.992) 1 hr survival	
					Point; turbine intake EL 603'			0.953 (90% CI 0.928-0.973) 1 hr survival	
					Point; turbine intake EL 603'			0.972(90% CI 0.949-0.989) 1 hr survival	
					Point; turbine intake EL 603'		13.5 kcfs Discharge	0.946 (90% CI 0.922-0.965) 1 hr survival	
					Point; turbine intake EL 603'		19 kcfs Discharge	0.949(90% CI 0.925-0.979) 1 hr survival	
					Pooled			0.961 (90% CI 0.951-0.969) 1 hr survival	
1997	Muir et al. 2001	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver downstream of juvenile bypass outfall	Normal	Not estimated	0.927 (SE 0.027)

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Little Goose Dam									
1993	Iwamoto et al. 1994	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver off juvenile bypass outfall	Normal load response	Not estimated	0.920 (SE 0.025)
1997	Muir et al. 1998	PIT	P	SHT	Point; turbine intake	Lower tailrace midriver downstream of juvenile bypass outfall	Normal load response	Not estimated	0.934 (SE 0.016)
1997	Muir et al. 1998	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver off juvenile bypass outfall	Normal load response	Not estimated	0.920 (SE 0.025)
Lower Monumental Dam									
1997	Muir et al. 2001	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver downstream of juvenile bypass outfall	Normal load response	Not estimated	0.865 (SE 0.018)
Ice Harbor Dam									
1968	Long et al. 1968	--	P	Coho	Units 1-3	Frontroll	Normal load response	0.810-0.900	Not estimated
2003	Absolon et al. 2003	PIT	P	YCS	Unit 1	Frontroll	Normal load response	Not estimated	0.89 (95% CI 0.84-0.94)
2003	Absolon et al. 2003	PIT	P	YCS	Unit 3	Frontroll	Normal load response	Not estimated	0.86 (95% CI 0.81-0.90)
2003	Absolon et al. 2003	PIT	P	SYCS	Unit 1	Frontroll	Normal load response	Not estimated	0.89 (95% CI 0.85-0.94)

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
McNary Dam									
1955	Schoeneman et al. 1961	Tatoo	P	YCS	Hose-unit not specified	Control-not specified	0.80 percentage wicket gate opening	Not estimated	0.87
1956	Schoeneman et al. 1961	Tatoo	P	YCS	Hose-unit not specified	Control-not specified	0.75 percentage wicket gate opening	Not estimated	0.92
1999	Normandeau 1999	B	P	YCS	Turbine intake upstream of wicket gate	Stay vane-mid runner blade	12 kcfs	0.98 (90% CI 0.955-1.005) 1hr survival	Not estimated
					Stay vane-runner tip			0.98 (90% CI 0.955-1.005) 1 hr survival	
					Stay vane-runner hub			0.978 (90% CI 0.952-1.004) 1 hr survival	
2002	Normandeau 2002	B	P	YCS	Point release all three intake bays	Draft-tube exit	8 kcfs	0.944 (90% CI 0.914-0.977) 1 hr survival-April	Not estimated
								0.955 (90% CI 0.931-0.982) 1 hr survival-April	
							11.2 kcfs	0.930 (90% CI 0.900-0.970) 1 hr survival-May	
								0.944 (90% CI 0.914-0.977) 1 hr survival-April	
							16.4 kcfs	0.945 (90% CI 0.945-0.964) 1 hr survival-April	
								0.953 (90% CI 0.915-0.994) 1 hr survival-April	

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
McNary Dam (Continued)									
2002	Absolon et al. 2002	R	P	YCS	Unit 9 point release all three intake bays	Tailrace 2 km below dam;	11.2 kcfs 16.4 kcfs	Not estimated	To 15 km down- stream: 0.871 (SE 0.016) To 46 km down- stream: 0.858 (SE 0.034) To 15 km down- stream: 0.856 (SE 0.011) To 46 km down- stream: 0.814 (SE 0.037)
2003	Peery et al. 2003 Draft Report	R	P	SYCS	Unit 9 point release	Frontroll	Normal load response	Not estimated	0.816 (95% CI 0.755-0.877
John Day Dam									
2002	Counihan et al. Draft Final	R	P	SHT	Rock Creek	Tailrace 1 km downstream from dam	Normal load response	Not estimated	Powerhouse 0.90 (95% CI 0.81-0.97) Spill: 30 day/ 30 night 0.93 (95% CI 0.85-1.00) Spill: 0 day/60 night
2002	Counihan et al. Draft Final	R	P	SYCS	Rock Creek	Tailrace 1 km downstream from dam	Normal Load Response	Not estimated	Powerhouse 0.97 (95% CI 0.89-1.03) Spill: 30 day/30 night Powerhouse 0.87 (95% CI 0.80-0.93) Spill: 0 day/60 night
2002	Counihan et al. Draft Final	R	P	YCS	Point; turbine intake U15	Tailrace 1 km downstream from dam	Normal load response	Not estimated	0.778 (SE 0.051) Spill: 0% day/ 60% 0.832 (SE 0.042) Spill: 30% day/30%
2003	Counihan et al. Draft Final	R	P	YCS SYCS	Point; turbine intake U4 and U15	Tailrace 1 km downstream from dam	Normal load response	Not estimated	0.820 (SE 0.043) Spill: 0% day/60% 0.764 (SE 0.046) Spill: day/45% night 0.719 (SE 0.024) Spill: 0% day/60% 0.722 (SE 0.024) Spill: day/30% night

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
The Dalles Dam									
2000	Counihan et al. 2002	R	P	YCS	Point; several turbine intakes	Downstream of dam at proposed bypass outfall	Normal Load Response	Not estimated	0.869 (95% CI 0.718-1.020)
2000	Absolon et al. 2002	PIT	P	YCS and Coho	Point; several turbine intakes	Downstream of dam at proposed bypass outfall	Normal Load Response	Not Estimated	0.790 (95% CI 0.748-0.834) day 0.830 (95% CI 0.785-0.878) night
				SYCS					0.791 (95% CI 0.703-0.890) day 0.889 (95% CI 0.790-1.000) night

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
					Bonneville Dam First Powerhouse				
1939-1945	Holmes 1956	Fin Clip	P	SYCS	Various, upstream OR, WA, spillway, turbine	Various tailrace locations	Normal load response	Not estimated	0.88
1999-2000	Normandeau 2000	B	P	YCS	Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	Original Kaplan 6.2 kcfs	0.947 (SE 0.0164) 0.964 (SE 0.0144) 0.986 (SE 0.019)	Not estimated
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	Original Kaplan 7.0 kcfs	0.933 (SE 0.0166) 0.959 (SE 0.0137) 1.009 (SE 0.077)	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	Original Kaplan 10.5 kcfs	0.963 (SE 0.0145) 0.986 (SE 0.0106) 0.968 (SE 0.0106)	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	Original Kaplan 12.0 kcfs	0.909 (SE 0.0189) 0.968 (SE 0.0139) 1.004 (SE 0.0063)	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	MGR Kaplan 6.2 kcfs	0.955 (SE 0.0155) 0.981 (SE 0.0116) 0.986 (SE 0.018)	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	MGR Kaplan 7.0 kcfs	0.949 (SE 0.0149) 0.963 (SE 0.0134) 0.974 (SE 0.0144)	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	MGR Kaplan 10.5 kcfs	0.977 (SE0.0122) 0.977 (SE 0.0123) 0.986 (SE 0.0119	
					Stay Vane-Blade Tip Stay Vane-Mid-blade Stay Vane-Blade Hub	Draft-tube exit	MGR Kaplan 12.0 kcfs	0.947 (SE 0.0153) 0.977 (SE 0.0124) 0.980 (SE 0.0132)	

Table 9. Continued.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
					Bonneville Dam First Powerhouse (Continued)				
2002	Counihan et al. 2003	R	S	YCS	The Dalles Dam		Normal load response	Not estimated	75 kcts spill day/gas cap night spill 0.909 (95% CI 0.801-0.985) Gas cap 24 h spill 0.890 (95% CI 0.786-0.980)
2002	Counihan et al. 2003	R	P	YCS	Point; turbine intake MGR unit	Tailrace downstream of turbine discharge frontroll	Normal load response	Not estimated	1.06 (95% CI ± 0.057)
						Tailrace downstream of PH2 JBS outfall		Not estimated	1.01 (95% CI ± 0.031)
					Bonneville Dam Second Powerhouse				
1988, 1989	Ledgerwood et al. 1990	CWT and Cold Brand	P	SYCS	Upper Turbine - 1 m below gate slot	Tailrace 2.5 km downstream	Normal load response	Not estimated	0.91
					Lower Turbine - 1 m below tip of STS				0.91
					Upper Turbine - 1 m below gate slot	Frontroll			0.98
					Lower Turbine - 1 m below tip of STS				0.97
2002	Counihan et al. 2003	R	S	YCS	The Dalles Dam	–	Normal load response	Not estimated	Normal 75k day/gas cap night 0.970 (95% CI 0.929-1.008) Gas cap 1.011 (95% CI 0.972-1.051

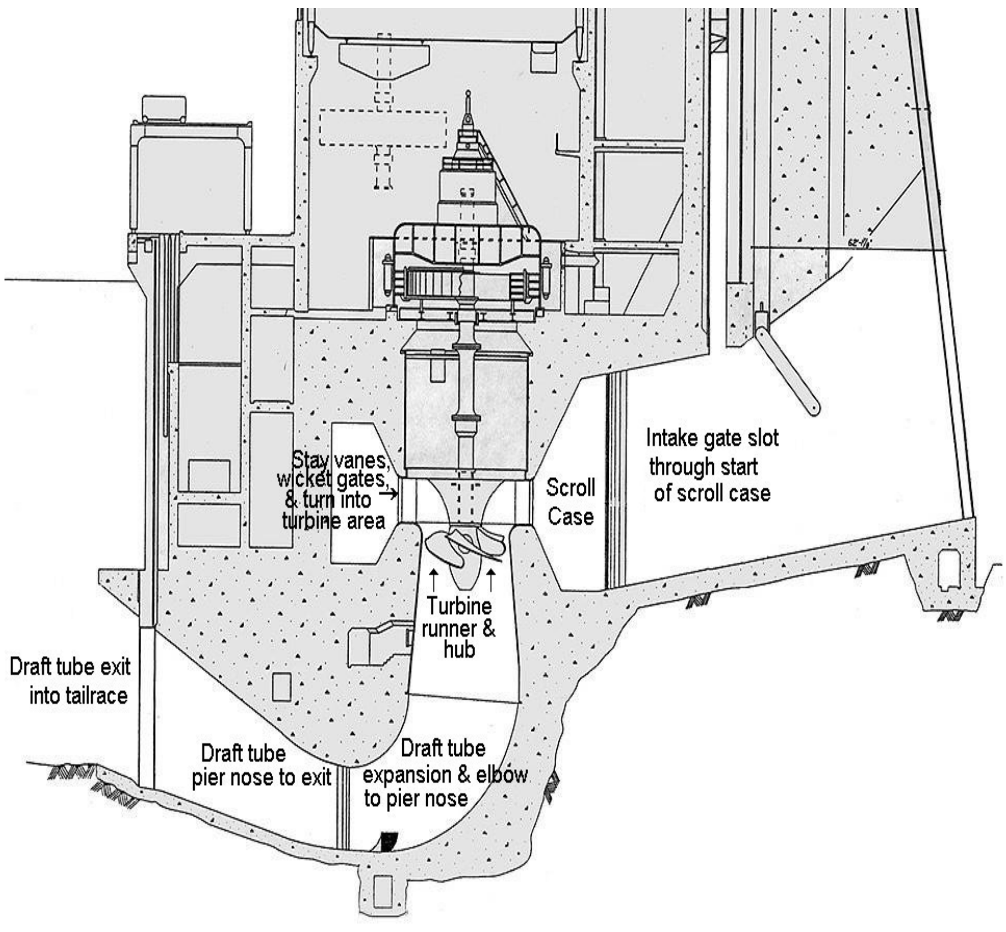

Figure 6. Cross sectional view of a Columbia River dam showing turbine passageway components (From Ploskey and Carlson 2004).

Juvenile salmon mortality associated with passing mainstem Columbia River turbines is potentially caused by several mechanisms (Ferguson 1993, USCOE 1995b, Cada et al. 1997). The turbine environment through which juvenile salmon pass varies physically with load, head, runner speed, and fish location within the intake. It also varies over time with environmental conditions such as temperature and fish condition. While efforts are underway to explore the relationships between these various factors and fish survival (for example, Carlson and Duncan. 2003), turbines are currently operated within 1% of peak efficiency based on the assumption that fish survival and hydraulic efficiency are correlated.

Results from recent studies question this basic assumption. Mathur et al. (2000) used balloon-tagged yearling chinook salmon to evaluate turbine survival at Lower Granite Dam. They found no significant differences ($P > 0.05$) between survival estimates for fish passing through a turbine operated at the low end of the 1% efficiency range, near peak efficiency, and at a high flow level outside the 1% range that caused cavitation. Maximum survival occurred at the low end of the 1% range.

Normandeau Associates et al. (2000) evaluated direct smolt survival through Bonneville Dam First Powerhouse turbines under four discharge levels and at three different release locations within the turbine (tip, mid-blade, and hub) using balloon tags. Direct turbine survival varied more with fish distribution (release location) than discharge, and maximum survival did not occur at peak efficiency. Normandeau Associates et al. (1996a) evaluated direct smolt survival through Rocky Reach Dam turbines under three discharge levels and at two different release locations within the turbine (3.0 and 9.1 m below the intake ceiling). Peak survival was observed to occur within the 1% range, but did not occur at peak efficiency. In contrast, in a similar study conducted at Wanapum Dam, Normandeau Associates et al. (1996b) concluded that maximum survival occurred outside of peak efficiency.

In 2002, Absolon et al. (2003) conducted an evaluation of fish survival through McNary Dam turbines. They found no difference in fish survival between two treatments. Estimated relative survival to detection locations 46 and 15 km downstream was 0.858 (se = 0.034) and 0.871 (se = 0.016) for the lower discharge and 0.814 (se = 0.037) and 0.856 (se = 0.011) for the higher discharge, respectively.

Normandeau Associates et al. (2003) conducted a series of balloon-tag tests in April 2002 which evaluated direct turbine survival of chinook salmon under four different operating levels of a single unit at McNary Dam. This evaluation provided direct survival estimates (90% CI) of 0.944 (0.914-0.977), 0.955 (0.931-0.982), 0.983 (0.957-1.000) and 0.945 (0.925-0.964) for operating levels of 8,000, 11,200, 14,000 and 16,400 cfs, respectively. None of the estimates were significantly different.

Skalski et al. (2002) conducted a retrospective analysis of recent balloon tag studies at four Snake and Columbia River dams and concluded that peak passage survival did not occur at peak turbine efficiency. They found as much as a 3.2% difference between the maximum survival and survival at peak turbine efficiency. Furthermore, a meta-analysis using results from 11 balloon tag survival studies conducted at different sites found no association between survival and efficiency ($r^2 = 0.0311$, $P = 0.2640$).

Operating near peak efficiency offers project operators guidelines that are convenient for management purposes, but as Skalski et al. (2002) pointed out, a statistical relationship between turbine efficiency and fish survival has not been observed. They recommended that turbines be operated where fish passage survival is maximum, and not solely on peak operating efficiency. While this recommendation is valid based on their analyses, currently, operations that correspond with maximum fish survival for turbines at Corps dams on the Columbia River have not been determined. Thus, given the complex and variable nature of the relationship between fish survival and turbine operations, guidelines for project operators are needed that provide the highest level of fish survival possible given the current information. Skalski et al. (2002) noted that operation of units within 1% of peak efficiency most often encompasses the turbine operation that corresponds with maximum turbine survival, which was the case at McNary Dam in 2002 (Absolon et al. 2003).

Studies Related to New Turbine Designs

Since 1997, the Corps has evaluated juvenile fish passage through Kaplan turbines with an emphasis on identifying turbine structures and operations responsible for injuring fish (USCOE 2003). Their Turbine Survival Program (TSP) has focused on hydraulic model studies, engineering evaluations, and biological investigations to relate survival and injury to physical conditions encountered during turbine passage. Since 1994, the U. S. Dept. of Energy (DOE) has funded studies under the Advanced Hydropower Turbine Systems Program (AHTS) to develop environmentally friendly turbines, with the goal of improving hydropower's environmental performance.

Under the TSP, Carlson et al. (2002) compared three-dimensional tracks of juvenile steelhead and chinook salmon with neutrally-buoyant drogues passing through a turbine at McNary Dam under two different operations. They found a significant difference in the elevation component of trajectories and time to pass the turbine intakes between the juvenile salmon and drogues and recommended that particles placed in physical models cannot be used to simulate the elevation component of the trajectories of smolts passing through turbines. They also conducted a sensitivity analysis of total fish survival through turbines and passage through the tip and hub areas of the turbine runner, and found that total survival through a turbine was relatively insensitive to the proportion of fish passing the tip and hub areas of the turbine runner.

Carlson and Duncan (2003) released sensor fish through turbines at McNary Dam in 2002 in conjunction with Absolon et al. (2003) and Normandeau Associates et al. (2003). They observed several differences in the physical conditions fish were exposed to under the two different operations. Exposure to draft tube turbulence was lower in both duration and magnitude and less dependent on intake (bay) location at a turbine discharge of 16,400 cfs compared to 8,000 cfs. These observations agreed with physical model data. When compared to similar exposure metrics for spill at Bonneville and The Dalles Dams, draft tube turbulence at McNary Dam under low turbine discharge may not be a major source of injury. Acceleration impulses believed to be associated with the stay-vane-wicket-gate cascade were more frequent at the lower discharge, possibly indicating increased potential for strike, scraping, and shear. They also caution that at higher discharge there is potential for increased risk of downstream predation resulting from depth acclimated fish "burping" air in their swim bladder during turbine passage. To reacquire air in the bladder to maintain a neutral buoyancy, fish would have to come to the surface and gulp air, potentially increasing their exposure to predators.

Coutant and Whitney (2000) conducted a literature-based evaluation to develop biological information regarding normal behavioral patterns of fish for use in engineering designs to improve the survival of fish passing through turbines. This work was not part of the TSP but was related. They suggested that models of fish trajectories should not assume neutral buoyancy for the period fish are passing through a turbine. This is because fish use their lateral line to sense obstacles and flow patterns, and this system may not be effective during the rapid passage times and pressure regimes associated with a turbine environment. The authors felt there are practical limits to observations and measurement of fish and flows in the vicinity of the turbine runner environment when developing information that can then be applied to designing a more fish-friendly turbine.

A minimum gap runner (MGR) is a Kaplan turbine design which minimizes the clear openings between the rotating blade tip and stationary discharge ring, and between the base of the blade and the hub. This reduces the opportunity for fish to be entrained in potentially harmful areas of high velocity discharge through narrow gaps (Eicher Associates Inc. 1987, USCOE 1995b). This is accomplished by incorporating a spherical hub, a specially shaped runner cone which allows water passing the blades to exit with a constant velocity and without excessive turbulence, and a spherical-shaped discharge ring to close the gap at the blade tips. Minimum gap runners are being installed in all ten units of the Bonneville First Powerhouse. The efficiency curves of an MGR design are steeper and have more of a “peak” than standard Kaplan designs. Operating within 1% of peak efficiency for fish passage using this steeper curve reduces the turbine operating range.

Fish survival through a MGR turbine at Bonneville Dam First Powerhouse was tested during the winter of 1999-2000 using balloon tags (Normandeau Associates et al. 2000). The MGR (Unit 6) was compared to a standard unit (Unit 5). The blade-to-wicket gate relationships for the standard unit were adjusted or “tuned” prior to the test. Survival of juvenile chinook salmon through the MGR turbines was evaluated for three different release locations (tip, mid-blade, and hub) under four different discharge levels: 6,200, 7,000, 10,500, and 12,000 cfs. Survival varied more with fish distribution (release location) than discharge. For both types of turbines, survival was higher for fish released near the hub and mid-blade locations than for fish released at blade tips (Table 10).

Maximum survival occurred at peak unit efficiency for the blade-tip and mid-blade releases. Maximum survival for the hub releases did not occur at peak efficiency, and in fact, the lowest survival was at peak efficiency. Skalski et al. (2002) conducted additional analyses of the Bonneville Dam MGR data and found no significant relationship between salmonid survival and turbine efficiency at any of the three release locations, nor between survival and average head, blade angle, discharge, or power generated.

Survival and injury comparisons between the MGR unit and the standard unit indicated that MGR survival was equal to or better than the standard unit. Absolute survival for fish passing near the MGR blade tip was up to 3% higher than for the same location in the standard unit. Overall, survival was not significantly different between the units, however, the incidence of fish injury was lower for fish passing through the MGR unit (0.014) compared to the standard unit (0.025).

In coordination with the DOE Program discussed below, a minimum gap runner turbine will be installed by Grant PUD at Wanapum Dam in 2005. This new design incorporates modifications to the blades and hub where the gaps are closed similar to the MGR installed at Bonneville Dam. In addition, significant modifications have been made to the alignment of the stay vanes and wicket gates to increase unit efficiency. Prototype biological testing is scheduled to begin in 2005.

Several other studies have been conducted under the DOE AHTS recently. Ploskey and Carlson (2004) modeled the probability of blade strike for the Bonneville Dam First Powerhouse turbines and compared these predictions to empirical data collected in 1999 and 2000 by Normandeau and Associates (2000). Blade-strike models predicted the probability for injury from strike increases with decreasing unit discharge and with increasing distance from the center of the runner where the fish passes the blade. They also predict that injury from strike was from two to five times higher than that observed in the empirical data. There was not a strong relationship between injury and discharge in the empirical data. The authors speculated that injury from blade strike could decline with increased discharge, but might be masked by increases in injury from other causes. They point out that researcher's inability to assign causal mechanisms to

Table 10. Ranges in estimated survival for 3 turbine release locations; each range represents the 4 turbine loads tested (Normandeau Associates et al. 2000).

	MGR	Unit 5
Hub releases	0.974 - 0.986	0.968 - 1.009
Mid-blade releases	0.963 - 0.981	0.959 - 0.986
Tip releases	0.947 - 0.977	0.909 - 0.963

observed injuries hinders relating injury or mortality to discharge. They concluded that efforts to empirically determine fish distributions at the turbine intake trashracks, wicket gates, and runner blades are needed before models can be used more effectively to identify turbine operations and designs that reduce injury and mortality rates.

Weiland and Carlson (2003) evaluated the feasibility of using ultrasonic tracking and acoustic cameras to observe fish and neutrally buoyant drogues during passage through turbines at McNary Dam. They found that while range of detection was high (30.5 m) for both technologies, spatial resolution was low and affected by noise within the turbine environment and would have to be improved to increase the utility of these technologies.

Abernathy et al. (2001) examined the responses of fish acclimated and not acclimated to gas supersaturation to rapid pressure changes to investigate the relative importance of pressure as a source of turbine passage mortality and injury. They found that the level of gas supersaturation that causes acute gas bubble trauma varies among species, as does the frequency, type, and severity of injuries associated with turbine passage. They concluded that if gas saturation is not a problem, exposure of juvenile salmonids to areas of low pressure associated with passing a turbine runner causes little direct mortality if fish are acclimated to surface pressures. However, if fish are acclimated to depth, injury rates increase due to expansion of gas in the swim bladders. Also, passage through areas of low pressure could produce injury and mortality under high saturation levels and if fish respond to supersaturation by seeking greater depths. For new turbine designs, they recommend that increasing the lowest point of the turbine pressure spike would reduce or eliminate fish injury and mortality caused by pressure.

Discussion

The primary question salmon managers and the Action Agencies need answered is whether existing operations provide the best protection for juvenile salmon migrating downstream, or whether alternative operations are warranted based on the available data. The data in Table 9 reflect the high variability associated with survival estimates through turbines relative to specific operating loads, conditions, and methods used to make the estimates. Skalski et al. (2002) found no statistically significant relationship between turbine efficiency and fish survival, which again reflects the high variability in the data. The data and analyses reported in the literature support two points: 1) operating within 1% of peak unit efficiency is a reasonable surrogate operation to maximize fish survival until additional, detailed information on the relationship between fish survival and turbine unit operations is developed, and 2) additional, rigorous biological index testing will be required to determine the optimal turbine operations for each species and life-history type of salmon and each set of turbines.

The need for biological index testing for each set of turbines presents a dilemma to salmon managers and hydro operators. The sample sizes required to distinguish small differences between test conditions can only be achieved at a high cost in terms of the number of fish required. For example, Perry et al. (2003) estimated that 244,000 subyearling chinook salmon would be required to detect a difference between treatments of 1% using a 2-tailed test when $\alpha = 0.05$ and $\beta = 0.80$. This number is reduced by use of a 1-tail tested test, and is significantly reduced by use of a significant t-test and by adjusting α, β, or the difference between treatments, but still remains high. For example, when $\alpha = 0.05$ and $\beta = 0.80$ and using a 1-tailed test, more than 21,000 subyearling chinook salmon would be required to detect a difference of 2% between treatments with a significant t-test. Thus, managers should discuss whether reliance on differences between treatments that are statistically significant is warranted given this situation.

Based on direct comparison of balloon-tag data and radiotelemetry data, a large difference between estimates based on the two methods was found at McNary Dam in 2002 (Ferguson et al. in prep.), where survival estimates based on balloon tags were higher than similar estimates based on radiotelemetry. Based on indirect comparisons of the estimates using the two methods, Bickford and Skalski (2000) observed that survival estimates based on balloon tags were on average 6% higher than estimates based on telemetry. This suggests indirect mortality can be a significant component of total estimated turbine mortality.

Use of the paired-release protocol requires that reference groups be released downstream of the test turbine. Typically one of two locations is selected, the front roll of the turbine boil or below the immediate tailrace and from 1 to 2.5 km downstream. There is no single best location for release of reference groups. The locations will be selected by the researchers to meet the objectives of the specific study for the powerhouse being evaluated. However, we view the immediate tailrace as being part of the turbine passage experience since it is heavily influenced by turbine discharge. Therefore, from our perspective, we try to release reference groups approximately 2 km downstream to incorporate any immediate tailrace effects into the treatment.

Releases of treatment groups made upstream of the dam represent the distribution of the general population, but also incorporate forebay and reservoir mortality into the treatment unless these are not partitioned out of the estimate. Point releases made into turbine intakes allow for specific areas of the passage environment to be evaluated. Data presented in Table 1 present few opportunities to directly compare estimates made within the same year using both release strategies.

Counihan et al. (2003a) estimated survival through the Bonneville Dam First Powerhouse in 2002 using releases made in The Dalles Dam tailrace and into the Bonneville Dam turbine intakes. Comparing the two, estimated survival based on the upstream releases was roughly 0.90, compared to 1.00 for the intake releases. We have no explanation for this difference, but note the estimates based on the intake releases look unusually high. When we discussed these high turbine estimates with the lead researcher, he indicated that powerhouse operations were unique that year, and due to low river flow most of the powerhouse flow was through the second powerhouse. He speculated this may have caused predators to move away from Bonneville First Powerhouse, resulting in the high estimated survival.

If we compare estimated survival through Bonneville Second Powerhouse turbines in 2002 based on releases in The Dalles tailrace (Counihan et al. 2003a) with estimates of survival based on intake releases (Ledgerwood et al. 1990), the results were similar (>0.97), although we caution that different methods and test fish were used, and different environmental conditions existed during these two years. Based on these limited data we cannot *a priori* recommend one release strategy over the other, since both release locations have merit, depending on the question being addressed.

Although few studies made releases during both day and night, the available information suggests that tailrace predation may be a component of turbine mortality if the tailrace is included in the treatment. We base this statement on trends observed in a study of survival at The Dalles Dam in 2000. Absolon et al. (2002) estimated that relative survival of PIT-tagged yearling chinook and coho salmon through turbines (turbine releases compared to tailrace releases made approximately 2 km downstream from the project) was 0.790 (95% CI, 0.748-0.834) for daytime releases and 0.830 (95% CI, 0.785-0.879) for night releases. Estimated relative survival of subyearling chinook salmon passing through turbines during the summer was 0.791 (95% CI, 0.703-0.890) and 0.889 (95% CI, 0.790-1.000) during the daytime and nighttime, respectively. Although nighttime survival was higher during both seasons, these differences were not statistically significant.

We also examined the available information for any relationship between turbine load (discharge) and survival. The most complete data for this comparison was provided by Normandeau Associates et al. (2000) from the testing of the MGR at Bonneville Dam First Powerhouse. Skalski et al. (2002) analyzed these data and found no significant relationship between salmonid survival and discharge. Normandeau Associates et al. (2003c) evaluated direct turbine survival of chinook salmon under four different operating levels of a single unit (Unit 9) at McNary Dam in April 2002. They also observed no significant differences between survival and operating levels of 8,000, 11,200, 14,000 and 16,400 cfs, respectively. However, both of these studies used balloon tags, and as discussed above, this methodology captures only a portion of the total mortality. If radio- or PIT-tag studies had been used for these tests, the increased mortality incorporated into the survival estimates based on these methods may have resulted in significant differences between turbine loads.

Comparing estimates of survival across the turbine blades, the data suggest that mortality increases from the hub to the tip of the blade, based on studies of the MGR and Unit 5 at Bonneville First Powerhouse.

Counihan et al. (2003a) estimated that survival through the Bonneville Dam Second Powerhouse for yearling chinook salmon released in the tailrace of The Dalles Dam was 0.970 during normal spill regimes and >1.000 under a spill to the gas cap operation. These high survival rates are similar to those reported by Ledgerwood et al.

(1990) when turbine and frontroll releases were compared. In comparison, Counihan et al. (2003a) reported that survival through Bonneville Dam First Powerhouse turbines was 0.909 and 0.890 for the two spill regimes tested in 2002. These data suggest that survival through the newer powerhouse is higher than through the First Powerhouse. However, completion of the installation of MGR turbines at the first powerhouse may improve survival through this route and differences between powerhouse estimates based on Counihan et al. (2003a) may have been due to tailrace conditions in 2002, as described above.

An important finding from the Corps TSP is that draft tubes are designed for specific turbine loadings and hydraulic performance of the draft tube increases with discharge. This is partly the reason that turbulence through turbines and passage times of neutrally buoyant beads are higher at lower discharges. This observation may be of considerable importance, and turbine investigators will likely focus on this in the future. Also, the most severe hydraulic conditions occur at the trailing edges of wicket gates and runner blades, within the hub "rope," and near the leading edge of draft tube splitter walls. These areas are being addressed through a new turbine being installed at Wanapum Dam in 2005. If performance of this prototype proves successful, modifications to these areas will likely be incorporated into future turbine designs by the Corps. However, as discussed above, significant progress in reducing total turbine mortality will have to include addressing indirect mortality that occurs downstream from the passage route.

Potential negative effects from fish diversion screens installed in turbine intakes on turbine passage survival is one aspect of this passage route that should be addressed. The estimated turbine survivals presented in Table 1 include screens installed in turbine intakes in all cases when screens are typically located in the intake. Thus, in all cases (except data for The Dalles Dam) the effects from screens have been incorporated into the estimates. Since the potential effect from screens has not been partitioned from the overall estimates, little can be discussed regarding this issue. However, we note that based on engineering studies, intake screens reduce turbine unit efficiency, which may affect juvenile salmonid survival.

Passage through Turbines Conclusions

1. Estimates of survival through turbines from studies conducted during the period of early FCRPS development, from 1939 through 1968, ranged from 0.81 to 0.92 (Holmes 1952, Schoeneman et al. 1961, Long et al. 1968, Table 9). Studies conducted under contemporary conditions using radiotelemetry and PIT-tag methodologies suggest mean survival through turbines generally remains in this range, but means as low as 0.72 have been reported. Therefore, turbines continue to represent a significant source of mortality for juvenile salmon migrating through the FCRPS.

2. Balloon-, PIT-, and radio-tag methodologies all have valid applications, depending on the study objectives. Radio and PIT tags are useful for incorporating both direct and indirect mortality in survival estimates. The balloon-tag methodology is a useful diagnostic tool to examine test fish for injuries and correlate injury types with physical parameters experienced during passage, but it is not a good estimator of overall survival rates. All studies require care with use of release mechanisms, selection of representative test fish, location of treatment and control releases, and verification of assumptions.

3. We do not place much weight on basing estimates of turbine survival on adult returns. The method is impractical given the high variability associated with adult returns and large sample sizes required to detect small differences between treatments. The Action Agencies and salmon managers should rely on juvenile recapture data to judge turbine passage effects and differences between treatments.

4. Indirect mortality is a significant component of total estimated turbine mortality. Future efforts to improve survival through turbines have to address this component if improvements are to be made to the turbine passage route.

5. A statistically significant relationship between juvenile salmonid survival and Kaplan turbine peak efficiency for Snake and Columbia River dams has not been demonstrated. This is because it is difficult to detect small differences between test conditions under highly variable conditions. Operation of units within 1% of peak efficiency most often encompasses the operation that produces the maximum estimated survival. Thus, continued operation within 1% of peak turbine efficiency is a reasonable operating guideline to follow until more detailed information on the relationship between unit operations and maximum fish survival for each family of turbines at FCRPS dams is developed. To develop more refined guidelines, additional, rigorous biological testing for each set of turbines will be required. These

tests appear warranted because maximum survival can be as much as 3.2% higher than survival measured at peak efficiency. This potential improvement in survival is large compared to other potential FCRPS configuration modifications to improve survival.

6. Since 1997, a significant amount of progress has been made toward understanding the casual mechanisms of mortality associated with fish passage through turbines. However, we have not seen a significant reduction in turbine passage mortality associated with any new turbine designs tested to date. Additional studies will be needed and new designs developed before turbine passage survival is improved to levels similar to alternative passage routes. There are no easy solutions to this challenge, which should be viewed as a long-term process. In 2005, the most recent turbine design to improve fish passage will be evaluated at Wanapum Dam.

ADULT PASSAGE

Background

All eight Columbia and Snake River mainstem dams from Bonneville through Lower Granite Dam provide upstream passage for adult salmon and steelhead through one or more fishways. The fishway systems are operated according to criteria developed by the COE, NOAA Fisheries, and state and tribal fishery co-managers. Each criterion is based on results of biological testing to determine the hydraulic conditions that maximize fish attraction and minimize delay. The COE annually coordinates with salmon managers and publishes the Fish Passage Plan (FPP). The FPP provides detailed operating procedures and criteria for adult fish passage facilities and special operations to accommodate research. This includes criteria on water depth and head on the entrance gates, powerhouse collection channels, floating orifices, ladder flow, counting windows, and fishway exits.

There is a significant backlog of unfunded maintenance and repair projects on entrance gates and gate lifting machinery at Snake and Columbia River dams. Also, at some Snake River project entrance gates the auxiliary water supply (AWS) systems cannot supply sufficient attraction water to meet the required minimum of 1.0-ft head differential between the adult collection channel and tailrace. This situation occurs during low tailrace conditions, when river flows are low and the downstream project is operated within the lower foot of the operating range of the reservoir.

At Lower Granite, Little Goose, and Lower Monumental Dams on the Snake River, all fishway entrances are served by a single AWS pump station. Fishway entrances located on the opposite side of the spillway from the pump station cannot satisfy the established flow criteria. During high river flow conditions, submergence and head differential criteria for south entrances at Lower Monumental and the north entrances at Little Goose and Lower Granite Dams are not met as pumps cannot get enough water into the AWSs. During low river flow, and with reservoirs at minimum operating pool, submergence criteria for south entrances at Lower Monumental Dam and the north entrances at Little Goose and Lower Granite Dams are not met.

The NMFS 2000 BiOp requires the COE to provide an emergency source of water at each project to satisfy fishway criteria if the main AWS system fails. Engineering studies have been completed for all projects except Little Goose and Lower Granite Dams. The Walla Walla District has selected a contractor to complete the design studies for these projects. John Day and McNary Dams were able to meet the BiOp requirement with existing facilities. Engineering alternatives for meeting emergency AWS capability at The Dalles Dam and Bonneville Second Powerhouse are being evaluated.

Research Results and Discussion

Dam Passage

Migration behavior of adult salmonids in the Columbia and Snake River drainages has been documented using uniquely-coded radio transmitters. The transmitters are implanted in the fish's esophagus and transmitters are detected using an extensive array of fixe-site antennas. Matter and Sandford (2003) compared the upstream travel times of PIT-tagged and radio-tagged spring/summer chinook salmon from Bonneville to Lower Granite Dams in 2000. They found no evidence that radio tagging negatively affected chinook salmon behavior.

Salmonids moving up through the Columbia and Snake Rivers tend to stay near the shore. This seems to hold true for all species and runs. This trend is documented by tracking radio-tagged fish, and data from individual fish tracks indicate crossing between sides of the river or reservoir occurs at what appear to be random locations. Natural migration behavior is a consideration when designing fishway entrances and exits, and Keefer et al. (2003a) showed that existing fishway entrances located near shorelines had high net entrance rates (number of fish entering orifices minus number of fish leaving), and high fishway entrance efficiency (entrances that produce passages).

For upstream migrating adult salmonids, the first approach to a dam changes as the proportion of river discharge changes from powerhouse to spillway. With no spill, most fish approach the dam on the shoreline adjacent to the powerhouse, and as spill starts a portion of those fish move to the shoreline adjacent to the spillway. At moderate spillway discharge, more fish approach the dam at the junction of the powerhouse and the spillway. Under rare, high flow and high spill events, when turbidity is also usually high, upstream movement of adults can slow considerably for a few days until the event subsides. Radiotelemetry studies at lower Snake River dams have indicated passage delays associated with high spill (≥40 kcfs) and highly fluctuating spill (Turner et al. 1983,1984).

Once at the dam, fish search across the downstream face looking for passage routes. Entrance preferences are for deep/wide openings with significant attraction flow. Shallower/smaller openings tend to have low numbers of entrances and negative net entrance rates. Median times for chinook salmon to first enter fishways ranged from 1.9 to 2.6 h at Ice Harbor and Lower Granite Dams in 1993 and 1994 (98.7 and 98.9% entered in less than 5 d). At Lower Monumental and Little Goose Dams, 98.5 and 98.2% entered in less than 5 d, and median times to first entries were 4.6 and 3.9 h, respectively (Bjornn 1998b).

Radiotelemetry studies in 1993 and 1994 have shown that adult fish both enter and exit the floating orifices in the powerhouse collection channels of Snake River dams. The net entry rate indicated that for fish entering the collection channel via the orifices, more fish left via the orifices than stayed in the collection channel (Bjornn et al. 1998b). The COE Fish Passage Operations and Maintenance (FPOM) committee concluded that closing the floating orifices at Snake River dams would improve the operation of the adult fishways because more water would be available for the main fishway entrances and maintenance would be improved because the bulkhead could be sealed and the collection channels dewatered on a more frequent basis.

First entry times in the lower Columbia River are comparable to those at the three lower Snake River dams. At Bonneville Dam, chinook salmon median first entry times were 2.0 and 2.2 h in 1996 and 1997, respectively; steelhead median first entry times were 1.9 and 0.3 h in 1996 and 1997, respectively. First entry times ranged from 0 (when the first at-dam record was in the collection channel) to 20 d for chinook salmon and 17.8 d for steelhead.

Bjornn et al. (1998d) concluded that when powerhouses are not at full load, changing the end of the powerhouse where turbines were operating had little, if any, influence on the time for steelhead to approach, enter, or pass fishways at Snake River dams. They saw a slight change in first approach sites, but not first entrance locations. Bjornn et al. (1998e) did not detect any differences in chinook and sockeye salmon or steelhead entrance locations or passage times when turbine unit 1 (and its associated discharge located near the south shore adult entrance) at John Day Dam was operated at 150 and 100 MW.

Fishway fences installed adjacent to the north powerhouse entrances at Little Goose and Lower Granite Dams in 1991 to reduce fallouts as fish moved upstream in the collection channel were not effective (Bjornn et al. 1995). Funneling the down-channel moving fish away from the entrances at the downstream end of the collection channels at Little Goose Dam in 1994 improved the net entrance rate at those entrances (Bjornn et al. 1998b).

A high rejection rate of the transition area between the collection channels and the fish ladders has been documented for spring/summer chinook salmon and steelhead (Stuehrenberg et al. 1995, Bjornn et al. 1998b). For steelhead, the rejection rates range from 46 to 71% for their first approach to the transition area at Snake River dams. Similar rates were found for chinook salmon at both Columbia and Snake River dams in 1996 (Keefer et al. 2003a).

In 1994, the University of Idaho Cooperative Fish and Wildlife Research Unit installed radiotelemetry antennas in the transition pools of the four lower Snake River projects and tracked the progress of 220 to 246 steelhead at each project. From 36 to 61% of the fish turned around in the transition pools, moved downstream, and exited the fishway at least once and an additional 8 to 27% moved downstream in the fishway but did not exit (Bjornn et al. 1998f).

From 4 to 35% of spring/summer chinook salmon turned around in the transition pool and headed downstream at McNary Dam and Ice Harbor Dam. At Bonneville Dam and Lower Granite Dam, 53 to 55% turned around in the transition pool (Keefer et al. 2003a). Similarly, fall chinook entering fishways at lower Columbia River dams turn downstream in the transition pool more so than any other fishway segment (Brian Burke, NOAA Fisheries, pers. commun., October 2003).

Several hypotheses have been offered to explain this transition and junction pool behavior: a) velocities are too low and unsteady, b) flow rates and velocity are inadequate to attract fish to the submerged section of the ladders and through the orifices at the base of the submerged ladder weirs, c) seasonal and intermittent temperature gradients between the ladder flow and the diffuser flow, d) high flow rates through large floor diffuser areas obscure attraction flow at the base of the ladders, and e) fish may be wary and reluctant to move into confined ladder pools.

Jumping within and from fishways is another adult passage issue. This behavior is typically associated with the transition from overflow weirs to vertical slot weirs, and with diffuser flow at the top of fishways (Dresser and Stansell 1998). This occurs primarily with steelhead at both John Day Dam fishways. However, at Lower Granite Dam faster passage times and more direct passage routes were observed for both chinook salmon and steelhead when weir panels were in the down position (Naughton and Peery 2003).

Migration Rates

The earliest study of migration rates in the Snake River prior to impoundment was conducted from 1954 to 1957 (Oregon Fish Commission 1960). Chinook salmon migration rates averaged 17.7 to 24.1 km d^{-1}. Steelhead migration rates varied with the season; spring rates averaged 11.3 to 16.0 km d^{-1}, whereas fall rates averaged 8.0 to 9.7 km d^{-1}. Steelhead tagged at McNary Dam in January, February, and April migrated at average rates of 3.2, 3.9, and 12.2 km d^{-1}, respectively. Sockeye averaged 19.3 km d^{-1} to a weir at Redfish Lake in Idaho.

The effect of season and water temperature on steelhead migration rates was also seen in studies conducted from 1969 to 1971, where steelhead had summer migration rates of 10.7 to 16.7 km d^{-1}, and late fall migration rates as low as 0.5 km d^{-1}. Bjornn and Peery (1992) concluded that in the Snake River prior to impoundment, salmon migrated from 18 to 24 km d^{-1}, and steelhead migration rates varied with season and water temperature and ranged from 11 to 17 km d^{-1} during the spring and summer to as low as 0.5 km d^{-1} during the late fall.

Spring/summer chinook salmon migration rates through the Snake River reservoirs in 1991 to 1993 ranged from 31 to 65 km d^{-1} while migration rates through free-flowing river sections above Lower Granite Dam ranged from 10 to 30 km d^{-1} (Bjornn 1998c). Travel through the Columbia River hydrosystem was slower, with median rates of 13 to 33 km d^{-1} for spring chinook in 1996-2000. Migration times from Bonneville Dam to McNary Dam ranged from 6 to 20 d for individual fish. For all groups, migration rate variation between years was correlated to mean flow and temperature; the date of migration was the most influential predictor of migration rates, followed by river discharge (Keefer et al. in prep) .

The median steelhead migration rate through Snake River reservoirs in 1993 was 30 km d^{-1} while migration rates through free-flowing river sections were generally less than 11 km d^{-1} (Bjornn 1998c). Based on the passage times at the dam and faster passage in the reservoirs than in free-flowing rivers, Bjornn et al. (1999) estimated that median time for salmon to pass the four dams and reservoirs in the lower Snake River in 1993 was the same or less with dams as without the dams.

In addition to the radiotelemetry data presented above, in 1998, 38 hatchery steelhead of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams (through December 31, 1998). Their median time for passage between the two dams was 32 d, or 14.4 km d^{-1} (ranged from to 5.7 to 40.7 km d^{-1} for the 460 km reach). Also in 1998, 22 spring/summer chinook salmon of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams. The median time for passage between the two dams (a total of 460 km) was 16.4 d, or 28.0 km d^{-1} (ranged from to 12.4 to 47.9 km d^{-1}).

Also in 1998, 38 fall chinook salmon of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams. Of these fish (1 wild and 37 hatchery fish), the median time for passage between the two dams was 12.0 d, or 38.3 km d^{-1} (ranged from to 13.9 to 51.1 km d^{-1}; Lowell Stuehrenberg, NOAA Fisheries, pers. commun., September 1999). This suggests that the 1998 migration rate of PIT-tagged steelhead through the FCRPS falls within the range observed in the Snake

River prior to construction of dams, and the migration rate of PIT-tagged spring/summer chinook salmon slightly exceeds the range reported by Bjornn and Peery (1992) for chinook salmon (run-type was not specified).

As reported above, Matter and Sandford (2003) compared the upstream travel time of PIT- and radio-tagged adult spring/summer chinook salmon from Bonneville Dam to Lower Granite Dam in 2000. Travel time for adult chinook salmon outfitted with PIT tags (15.9 d) was significantly longer than passage time for fish outfitted with radio transmitters (14.1 d). The authors concluded that this difference was probably related to differences in study design or data complications.

Raymond (1964) compared the median migration timing of sockeye and chinook salmon past Bonneville and Rock Island Dams between 1938 and 1950 when no other dams existed in the hydropower system corridor. The mean passage time between Bonneville and Rock Island Dams for sockeye salmon was 16.5 d (range 7 to 27 d). NOAA Fisheries computed the same statistic for the period between 1985 and 1999 and found a mean difference in passage time of 15 d (range 11 to 19 d). Quinn et al. (1997) also studied migration rates of Columbia River sockeye salmon. They found that travel time decreased from 1954 to 1994 between Bonneville and McNary Dams, but was unchanged between McNary and Rock Island Dams.

Fallback

A substantial percentage of adult salmon and steelhead passing dams have been observed to fall back through spillways and turbines at certain dams under certain conditions (Bjornn and Peery 1992). High fallback rates are usually associated with high river flows and spill, as well as the location of fishway exits relative to the spillways. For example, the south fishway at Bonneville Dam exits into the forebay at Bradford Island in close proximity to the spillway and has been associated with the highest fallback rates on the Columbia River. Bjornn et al. (1998a) found that fallback rates were 2.5 to 3.7 times higher for spring/summer chinook salmon that passed via the Bradford Island fishway than the Washington-shore fishway, and 16 to 20 times higher for sockeye salmon. When only fallbacks within 24 h of passage are considered, 92 to 97% of all fish that fell back at Bonneville Dam between 1996 and 1998 had used the Bradford Island fishway (Bjornn et al. 1998a). In 1996, almost all steelhead that fell back passed via the Bradford Island fishway.

Bjornn and Peery (1992) presented fallback rates from over 50 radiotelemetry studies of chinook and sockeye salmon and steelhead at various dams from 1966 through 1985. Keefer and Bjornn (1999) estimated (based on radiotelemetry) that adult counts at

Bonneville Dam were overcounted by 13.5 to 19.3% for spring/summer chinook salmon from 1996 through 1998, by 4.7 to 8.2% for steelhead from 1996 through 1997, and by 12.6% for sockeye in 1997 when fallback and reascension were taken into account. Similarly, from 1996 to 2001, passage overestimation at lower Columbia and Snake River dams ranged from 1 to 16% for spring/summer chinook salmon, 1 to 38% for fall chinook salmon, and 1 to12% for steelhead (Boggs et al. unpub. data).

Between 1996 and 2001, fallback rates for spring/summer chinook salmon in the lower Columbia River ranged from 2 to 20% and from 1 to 14% at Snake River dams. Fallback rates for steelhead during that same time period ranged from 5 to 13% at lower Columbia River Dams and from 2 to 9% at Snake River dams. From 1998 to 2001, fallback rates for fall chinook ranged from 2 to 12% at lower Columbia River dams and from 3 to 58% at Snake River dams (Boggs et al. unpub. data).

In addition to fish that fall back within 24 h of exiting the fishway, a large number of fallbacks occur after fish have migrated significant distances upstream. Dam operating procedures or environmental conditions at individual dams are unlikely to affect fallback associated with this behavior. The cause of this wandering behavior has not been determined. Potential causes include difficulty locating natal tributaries, natural survival adaptation, the use of hatchery broodstock not native to the drainage, and some level of homing impairment from having been transported. Mendel and Milks (1996) attributed much of the fall chinook salmon fallback they observed to poor entrance conditions at the Lyons Ferry Hatchery and extensive wandering up and down the Snake River and into tributaries. They estimated that the fallback at Lower Granite Dam was 16 to 39% in 1993, and 30 to 41% in 1992. They noted that over 80% of the radio-tagged fall chinook salmon that entered Lyons Ferry Hatchery each year had reached Little Goose Dam before descending downstream to the hatchery.

Keefer and Bjornn (1999) reported that for all seven dams studied in 1996, the median passage time at a dam was higher for spring/summer chinook salmon that fell back one or more times. The impacts of increased passage times due to fallback on adult delayed mortality and reproductive success are unknown.

Survival

Losses can be broken down into two segments 1) losses between dams, defined as the difference between fish counted at consecutive dams minus those accounted for between those dams (harvest and tributary turn off), and 2) losses between the upper dam and the spawning grounds or hatchery.

Losses between dams that are based on dam counts are susceptible to counting errors and assumptions. For example, the largest portion of over-counts at dams is likely due to multiple counts of fish that have fallen back over the dam and reascended the ladder. Since fallback rates vary with each dam, environmental conditions, and project operations, bias or error associated with dam counts is variable. Radiotelemetry provides a more accurate assessment of actual passage rates and behavior than dam counts, although use of radiotelemetry assumes that tagged fish represent the general population and tagging and release do not affect the behavior of the fish. Further, estimates of survival based on radiotelemetry may be conservative because they include both actual mortality and unaccounted-for losses, such as tag regurgitation, unreported harvest, and tributary turnoff that is missed or not monitored. Survival estimates based on detection of PIT-tagged adults is also accurate and increasingly possible as detectors are installed at more dams.

With respect to losses between the upper dam and the spawning grounds or hatchery, little early information is available. Survival to spawning for spring/summer chinook salmon was estimated at 55% for fish counted at Ice Harbor Dam from 1962 to1968 when only one Snake River dam was present, and 46% from 1975 to1988 when all four dams were in place, based on relating counts at Ice Harbor Dam with redd counts in Snake River tributaries (Bjornn et al. 1998c).

More recently, with all four Snake River dams in place, radiotelemetry has been used to estimate the survival of spring/summer chinook salmon from Ice Harbor Dam to spawning grounds or hatcheries. Bjornn et al. (1995) estimated survival through this reach was 77% in 1993, 73% in 1992, and 54% in 1991 for fish that were radio tagged at John Day Dam in 1993, and Ice Harbor Dam in 1992 and 1991. Caution should be used in comparing survival between the pre-development and post-development periods because of differences in technique and methodology.

For spring/summer chinook salmon radio tagged at Ice Harbor Dam, survival from Ice Harbor Dam to Lower Granite Dam was 80.8 and 74.4% in 1991 and 1992, respectively. For spring/summer chinook salmon radio-tagged at John Day Dam in 1993 survival from Ice Harbor Dam to Lower Granite Dam was 85.9% (Bjornn et al. 1999).

For spring/summer chinook radio-tagged at Bonneville Dam in 1996, 1997, and 1998, survival from Ice Harbor Dam to Lower Granite Dam was estimated two ways. First, for only those fish that passed the top of Ice Harbor Dam and moved upstream. Second, for all fish that approached Ice Harbor Dam (whether or not they passed the dam). Survival from Ice Harbor Dam to Lower Granite Dam for fish that passed the top of Ice Harbor Dam was 96.4, 97.7, and 98.4% in 1996, 1997, and 1998, respectively. Survival from Ice Harbor Dam to Lower Granite Dam for fish that approached Ice Harbor Dam was 92.8, 95.2, and 98.4% in 1996, 1997, and 1998 respectively (in 1998 both survival estimates were 98.4% because all fish that approached Ice Harbor either passed the top of the dam, or were harvested or detected downstream. Estimates for survival through the Snake River based on tagging conducted at John Day and Bonneville Dams probably do not include effects from trapping, tagging, and release since these likely occurred prior to entering the lower Snake River.

Bjornn et al. (1998c) found that the survival of spring/summer chinook salmon from Ice Harbor Dam to over Lower Granite Dam from 1991 to 1993 was similar between fish marked at Ice Harbor Dam with radio transmitters (83 to 87%) and unmarked fish (70 to 92%), based on comparing radiotelemetry data with dam counts. This suggests that there was no effect on survival estimates from trapping fish at Ice Harbor Dam.

The installation of a complete PIT-tag detection system at Bonneville Dam in 2001 combined with additional detection capabilities upriver has allowed adult survival from Bonneville Dam to Lower Granite Dam to be estimated based on PIT tags. Data from transportation studies conducted by NOAA Fisheries shows that for spring/summer chinook salmon adults, survival varied between 80 and 85%, with no effects of transportation as juveniles. Steelhead survival for this section was 70% for adults that were transported as juveniles, and 80% for non-transported fish.

Assigning mortality associated with fallback to dam operations or behavior is difficult because some fish may have “over-shot” and then return to lower river tributaries. Bjornn (1998a) observed fallback mortality of 8% for sockeye salmon at Bonneville Dam (a species with no spawning below Bonneville Dam). Mendel and Milks (1996) estimated fall chinook fallback mortality at 26 and 14% in 1993 and 1994, respectively, for fish that fell back through one or more of the four lower Snake River dams. This higher mortality for fall chinook occurred during periods of no spill, when the fallback was assumed to have been through turbines. Keefer and Bjornn (1999) used radio-tagged fish known to have passed Bonneville Dam in 1996 to estimate survival to tributaries or the top of Priest Rapids Dam. Steelhead and spring/summer chinook salmon that did not fall back over Bonneville Dam had survival rates that were 3.8 to

5.2% higher than fish that did fall back. Fish that did not fall back over any dam had survival rates from 3.0 to 5.4% higher than fish that did fall back.

Marine Mammal Predation

When considering all causes of salmonid decline in the Columbia River Basin, predation by marine mammals, while not considered a dominant regional cause, can be a significant local factor, especially when salmonid runs are low (NRC 1996). Marine mammals prey on salmonids near man-made structures such as dams or fish passage facilities where fish congregate, and the presence of marine mammals in the lower Columbia River and estuary during adult salmonid migrations raises serious concern for already depressed populations. However, the current precision of estimates of the percentage of salmonid spawner escapement consumed by marine mammals in the Columbia River Basin is poor. This is due in part to high temporal variability (interannual, seasonal, weekly, and day versus night foraging) and spatial variability in salmonid consumption, and the difficulties in sampling sufficiently to capture all major sources of variability.

Three species of pinnipeds, harbor seals, California sea lions, and Steller sea lions, occur in the Columbia River. Harbor seals are the most abundant pinniped species in the lower Columbia River, with peak haul-out counts exceeding 2,000 at Desdemona Sands, a tidal sandbar adjacent to Astoria, Oregon, which is the largest seal haul out. However, harbor seals in the Columbia River can forage many kilometers away from haul-outs, including upriver areas and coastal regions outside the river.

Markings (including apparent tooth and claw abrasions) commonly observed on returning adult salmon are indicative of marine mammal predation. Harmon et al. (1994) estimated annual injury rates of 14 to 19.2% for spring and summer chinook salmon and 5.4 to 14.2% for steelhead that arrived at Lower Granite Dam from 1990 to 1993. For the years 1994 through 2001, the injury rate for adult spring and summer chinook salmon at Lower Granite Dam ranged from 15.7 to 28.6% (Jerrel Harmon, Douglas Marsh, NOAA Fisheries, pers. commun.). Based on the size of some of the teeth marks, it is believed they were made by harbor seals. A NOAA Fisheries report to Congress (NMFS 1999c) under the Marine Mammals Protection Act concluded that pinniped populations are now abundant, increasing, and widely distributed along the West Coast where there is a high potential for impacts on salmonid populations.

Zero Flow Operations

Powerhouse discharge can be reduced to near zero during hours of darkness to preserve water for periods of higher power demand. Although the proportions of adult fish recovered were small, Bjornn et al. (1998g) found no statistically significant evidence that reducing flows to near zero at night affected adult steelhead migration rate, the proportion of fish passing dams, the proportion of fish captured in the fishery, or the proportion of fish returning to hatcheries in 1991, 1992, and 1993. A consistent pattern of slower steelhead migration in the early and late portions of the runs was found, which was associated with warm and cold water temperatures, respectively. Adult fishways were operated continuously throughout the tests. McMaster et al. (1977) also found no difference in the migration rates of chinook salmon and steelhead when discharge was reduced to near zero at night.

Water Temperature

Bell (1991) described the preferred temperature range and upper and lower lethal temperature limits for most salmonid species. For example, for chinook salmon the preferred range is 7 to 14.5ºC (45 to 58ºF), with a lower and upper lethal limit of 0 and 25ºC (32 and 77ºF). Summer water temperatures in the Snake and Columbia Rivers often exceed 21ºC (70°F), and water temperatures in adult fishways can be even higher than ambient river temperatures.

River water temperatures greater than 20°C increase travel times between dams for migrating salmonids (Peery et al. 2003). Affected fish may abort their migrations or seek cooler water that may not be in the direct migration route to their spawning site. Snake River fall chinook salmon and steelhead often slow their migration through the Columbia River and delay entering the Snake River when water temperatures are high (Stuehrenberg et al. 1978). These fish seek temporary refuges in lower Columbia River tributaries en route to their final destinations at up-river locations or hold in cooler Columbia River water off the mouth of the Snake River until Snake River water temperatures cool.

Of 125 chinook salmon recorded at Ice Harbor Dam in 1996, 20% had been recorded in lower Columbia River tributaries (Bjornn et al. 2000). For steelhead, 65% of fish passing Lower Granite Dam were observed in one or more lower tributaries (Keefer et al. 2002). In both cases, peak tributary use coincided with peak mean daily temperatures at dams (approximately 22°C), while recorded temperatures in the tributaries were less than 20°C. Delays associated with high water temperatures can subsequently affect reproductive success. Of 71 radio-tagged sockeye salmon that held in the Columbia River until the Okanogan River cooled in 1992, only 24 (33.8%) survived to the spawning grounds (Swan 1994). Delay caused by high water temperatures could also impact the reproductive success of fall chinook salmon which spawn in the fall, as discussed below. The effect of delays on steelhead, which spawn in the spring, are unknown.

The NMFS 2000 BiOp requires the COE to provide water temperature control in adult fishways. The University of Idaho Cooperative Fish and Wildlife Research Unit began monitoring temperatures in the forebays and adult fishways at Ice Harbor and Lower Granite Dams in 1995. Temperature changes along the length of the fish ladders were found to be slight: less than 0.5°C with differential increases to 2°C found on a few occasions (Keniry and Bjornn 1998). Temperature differences upstream and downstream from diffusers were also minimal.

However, the use of warm surface water from reservoirs affects temperature in the entire fishway, and a discontinuity may occur at the transition pools at the base of fish ladders. Here, cooler water is added to augment flow at fishway entrances. At Lower Granite Dam, this has resulted in temperatures up to 4°C warmer in transition pools than at fishway entrances (Peery et al. 2003). The COE also monitors water temperatures in the fishways at John Day Dam, which exhibits similarly steep thermal gradients near the bottom of its south fish ladder. Salmonid passage times at John Day Dam are longer as a result, and more fish exit fishways (interrupting passage) as temperatures increase, which further contributes to extended passage times (Keefer et al. 2003b).

Since 1992, Dworshak Dam has been operated to provide cold water for lower Snake River temperature control to benefit outmigrating juvenile fall chinook salmon. Up to 1.2 million acre feet of water at temperatures from 5.6 to 13.3°C (typically 8.9 to 11.1°C) have been used to augment flows and reduce high water temperatures. These releases are managed by regional salmon and reservoir managers to improve migration conditions for migrating smolts and adults, and are typically made during July and August. Karr et al. (1998) estimated that because of water releases from Dworshak Dam in 1994-1996, water temperatures were 3.1 to 5.3ºC cooler for 18 to 32 d at Lower Granite Dam, and 2.4 to 3.1ºC cooler for 14 to 43 d at Ice Harbor Dam. A literature review by McCullough et al. (2001) of the effect of temperature on salmonids found that laboratory and field studies show warmer water temperatures (>13-15.6ºC. C) cause a detrimental effect on the size, number and/or fertility of eggs. Warm water temperatures during the summer, therefore, have the potential to reduce reproductive success of salmonids.

Dauble and Mueller (1993) suggest that reducing mainstem water temperatures to below 21°C could reduce risk to populations of migrating adult salmon. It appears that operation of the Hells Canyon Complex has decreased late winter/spring temperatures and increased fall temperatures in the Snake River (Richie Graves, NOAA Fisheries, pers. commun., January 2000). Ted Bjornn (Idaho Cooperative Fish and Wildlife Research Unit, pers. commun., January 2000) found a similar trend when he plotted mean water temperatures at Ice Harbor Dam from August through October, and compared two periods:1962 to 1968 and 1975 to 1989. The 1975-89 period was cooler during August but warmer in September and October than the 1962-68 period.

Recently, comparisons have been made of the migration timing of steelhead and fall chinook salmon from Bonneville Dam to Ice Harbor Dam, based on radiotelemetry studies conducted from 1996 to 1998 and dam counts from 1991 to 1998. Plots were made comparing date, cumulative proportional count at Ice Harbor Dam, and river temperature (turbine scroll case). The plots indicated several general trends. First, steelhead passage at Ice Harbor Dam is slightly later than fall chinook salmon. Second, a high proportion of fall chinook salmon move into the Snake River when water temperatures exceed 20º C. This was particularly apparent in 1998 when over 80% of the fall chinook salmon crossed Ice Harbor Dam before water temperatures dropped below 20º C. Third, fish appeared to move rapidly upstream through the system relative to spring/summer chinook (also noted in Matter and Sandford 2003). If fall chinook salmon migrations over Ice Harbor Dam are later than normal, it appears their migration dates are delayed from Bonneville Dam upstream, rather than being delayed by specific warm water conditions at the mouth of the Snake River (Ted Bjornn, Idaho Cooperative Fish and Wildlife Research Unit, pers. commun., January 2000).

Dissolved Gas Supersaturation

Mortality of adult salmon from gas bubble disease (GBD) has occurred in the Columbia River intermittently since the first dams were constructed. However, effects of GBD on adult salmonids are less understood than are the effects on juveniles. Relationships between TDGS exposure, GBD signs, and mortality are not defined. Depth distributions of upstream migrants are poorly documented, thus, the mitigative effects of hydrostatic compensation at ambient TDGS is unknown. Also, insufficient data exists for determining a threshold TDGS level below which successful spawning is known to occur (NMFS 1997).

Following implementation of voluntary spill to enhance dam passage for juvenile salmonids, monitoring was initiated to examine upstream migrating adult salmonids for GBD signs. Beginning in 1994, adult fish were examined annually at Bonneville and

Lower Granite Dams and intermittently at Ice Harbor and Priest Rapids Dams. Under voluntary spill conditions where reservoir and tailrace TDGS is limited to 115 and 120%, respectively, signs of GBD were not seen and effects were assumed to be benign. Monitoring was also done at Three Mile Dam on the Umatilla River, OR. However, facilities to capture and examine adult salmonids at this site are limited. Thus, the ability to obtain representative samples from locations where the greatest impacts may occur, for example downstream from McNary Dam, is limited. Also, spawning success in relation to TDGS has not been monitored.

The only period in the 1990s when GBD signs were readily observed on adult salmonids was during the spring freshet in1997 (the highest runoff volume year in recent history; NMFS 1998a). However, GBD signs were documented only at a few sites and no estimates of impact could be made. During that period, TDGS downstream from Bonneville Dam exceeded 135% for 16 d and 130% for 24 d. TDGS exceeded 125% for extended periods at other river reaches.

At Bonneville Dam Second Powerhouse, daily prevalence of GBD was high for sockeye salmon (14 to 100% for more than 3 weeks) and steelhead (6 to 50% for 2 weeks). Chinook salmon during the same period showed relatively few signs, with 0 to 6.5% prevalence. No samples were collected from fish traversing the Bonneville Dam spillway tailrace, where TDGS was highest. No GBD signs were observed at Lower Granite Dam; however, fish were not examined until they had spent several hours in the low TDGS conditions of the fishway; GBD signs may have disappeared during fishway passage. At Priest Rapids Dam, sampling took place after TDGS decreased to moderate levels of 113 to 124%. In 1996, prior to spillway deflectors being installed, average TDGS downstream from Ice Harbor Dam was very high for almost one month, generally exceeding 135%. Adults examined at Lower Granite Dam showed no signs of GBD. However, this site is 172 km upstream from Ice Harbor Dam. Further, TDGS in the Little Goose reservoir (59 km long) was less than 125% for all but 3 d.

Head burn (exfoliation of the skin and underlying connective tissue) on the top or sides of the heads of adult salmonids has been observed in the Snake River during periods of high spill and was thought to be a sign of GBD at one time. Head burn was considered by the Gas Bubble Disease expert panel held by NOAA Fisheries in 1995, but given a low research priority ranking (NMFS 1996). Efforts to address the cause of head burn were transferred to the COE Fish Passage Operations and Maintenance Coordination Team which has discussed the potential causes of head burn. Elston (1996) conducted clinical evaluations of fish with typical head burns from Lower Granite Dam and suggested that head burns were caused by mechanical abrasion and laceration, rather than necrosis associated with subcutaneous emphysema from GBD.

Monitoring for head burn has been conducted at Lower Granite Dam by NOAA Fisheries since the early 1990s. From 1993 through 1999 the percentage of adult chinook salmon with head burn ranged from 0 to 9.8%. Monitoring for head burn has been conducted at Bonneville Dam by the Columbia River Inter-tribal Fish Commission since the mid-1990s. From 1997 through 1999 the percentage of adult chinook salmon with head burn was <1% (Larry Basham, Fish Passage Center, pers. commun, February 2000). This indicates that the incidence of headburn likely is occurring during passage through the hydrosystem. The exact cause of head burn remains unknown. Monitoring will continue to document the rate of injury. Research on the migration behavior of fish with head burn will be needed to relate the injury to survival. For example, Bjornn et al. (1995) found that of 66 radio-tagged chinook salmon that were noted as having head scrapes or injuries, 38% did not migrate to known spawning areas and were classified as possible prespawning moralities.

Kelts

Post-spawning, downstream migrations of steelhead have been documented throughout the existence of the FCRPS (Long and Griffin 1937, Whitt 1954, Evans and Beaty 2000, 2001, Wertheimer et al. 2001, 2002) and the potentially negative effects of the hydropower system on iteroparity rates recognized (NPPC 1986, ISG 1996). However, effects of the hydropower system on steelhead kelt survival and reproductive success are poorly understood. Only recently have studies been directed at conclusively identifying kelts (vs. pre-spawners or fallbacks) and documenting their downstream timing and project-specific passage. (Recent information for upper Snake River Basin areas indicates that repeat spawning rates in the Snake River probably average less than 2% (Evans and Beaty 2000).)

In 2000, the COE initiated a program to study the downstream passage behavior of kelts at Bonneville Dam. Overall, 39.5% of radio-tagged kelts passed through the spillway, 39.5% through Powerhouse I, and 21% through Powerhouse II. At Powerhouse I, 83% (43/52) kelts passed through turbine units, 8% (4/52) passed through the prototype surface collector into the ice and trash sluiceway, and 10% were guided by traveling screens into gatewells and the juvenile bypass system. Median forebay residence times were longest at Powerhouse I (8 h, 39 min), followed by Powerhouse II (4 h, 34 min), and were significantly shorter at the spillway (15 min; Wertheimer et al. 2001).

In 2001, low flow conditions provided an opportunity to evaluate kelt passage under low or zero spill conditions. Sluiceway passage efficiencies for kelts of 69 and 89% were estimated at The Dalles and Bonneville Dams, respectively (Wertheimer et al. 2002), and only 3% (7/212) of kelts released at Lower Granite Dam were detected below

Bonneville Dam.

Studies in 2002 focused on evaluating the abundance of kelts at McNary and John Day Dams (Wertheimer et al. 2003). An estimated 14,057 kelts were present in McNary reservoir and an estimated 13, 081 kelts passed John Day Dam during a 9-week period. Passage through John Day Dam under 24-h spill (30%) and nighttime spill (0% day / 54% night) were evaluated (Table 11). At The Dalles Dam, 30% spill kelt passage efficiency was 99% and sluiceway efficiency increased from 64 to 89%.

In spring 2003, Boggs and Peery (2003) examined 1,838 steelhead (using ultrasound) collected from the Lower Granite Dam juvenile bypass separator and reported 93% were kelts of which 17% were males, 83% females, and 50% were wild. They also reported that return rates for kelts PIT tagged and released in 2002 were 2.7% for kelts transported from Lower Granite Dam to the estuary, and 0.8% for kelts released in the Lower Granite Dam tailrace to migrate in-river.

In 2003, mean migration rates of radio-tagged kelts were slower in Snake River reaches (32.4 km/d) than in lower Columbia River reaches (55.2 km/d; Boggs and Peery 2003). Migration rates were positively correlated with river flow and generally increased in progressively downstream reaches (P<0.0001, R^2=0.63). Of the 112 kelts released in the Lower Granite Dam tailrace, 55% were detected in the tailrace of Ice Harbor Dam and 34% were detected in the tailrace of Bonneville Dam (with no difference in the migration rates or hydrosystem survival between hatchery and wild kelts). This compares with detections below Bonneville of 4.1 and 17% in 2001 and 2002, respectively. However, migration conditions in 2001 consisted of low flows and little spill, conditions in 2002 included BiOp spills and below average flows with a sustained late runoff, and conditions in 2003 included BiOp spills, below average flows and a large freshet in late May/early June when kelts were in the lower Snake and Columbia Rivers. Since migrating kelts predominately choose spill and sluiceway routes of passage when available and migrate faster with higher flows, spill, sluiceway operation, and flow augmentation appear to substantially improve kelt survival to below Bonneville Dam.

Table 11. Project kelt passage (PE), guidance (GE), sluiceway (SLE) and spillway (SPE) efficiencies, sluiceway (SLF) and spillway effectiveness (SPF), at John Day (JDD), The Dalles (TDA), and Bonneville (BON) Dams 2001-2002 (Wertheimer et al. 2003).

Project	Year	N	Spill (%)	PE (%)	GE (%)	SLE (%)	SLF	SPE (%)	SPF
JDD	2002	58	0:54	90	50	NA	NA	79	1.5:1
JDD	2002	97	30:30	95	58	NA	NA	88	2.9:1
JDD	2002	209	NA	93	46	A	NA	87	NA
TDA	2001	28	0	64	NA	64	16.8:1	NA	NA
TDA	2001	70	30	99	NA	89	19.3:1	87	2.9:1
TDA	2002	207	37	95	NA	52	20.0:1	90	2.4:1
BON	2001	73	2	58	53 (B2)	87 (B1)	124.3:1	NA	NA
BON	2001	68	37	88	55	100	349.9:1	54	1.6:1
BON	2002	207	45	90	58	100	250.0:1	67	1.5:1

Other Adult Passage Issues

The use of individually coded radiotelemetry tags for adult fish has greatly increased the precision associated with studies of migration behavior and survival at dams and through the mainstem corridor. Individual fish have been uniquely tagged, their approach behaviors and passage over dams and through reservoirs monitored, and their run histories reconstructed. A large amount of information has been obtained and reported but a number of uncertainties associated with adult passage at dams and through the hydropower system remain.

Adult passage through the lower river and passage efficiency at Bonneville Dam have not been fully investigated. Flow control has altered the lower river and estuarine hydrograph and potential adverse impacts include delay or increased mortality in the estuary. In addition, only fish captured in Bonneville Dam fishways are tagged and used to assess passage efficiency at this, the most downstream obstacle to passage. Studies are needed to confirm that passage efficiency estimates at Bonneville are not biased due to the exclusive use of "successful" fish (i.e., those that make it into the fishways where they are captured and tagged). This information is particularly critical if passage recorded at Bonneville Dam PIT-tag detection systems is used to compare relative smolt-to-adult survival rates (SARs).

Limited information is available regarding the effects on adult Pacific salmon from passing through turbines. Bell (1967) used mathematical formulas to estimate injury and mortality associated with turbine passage. In his formulas, the probability of strike increases with fish length. Thus we assume that mortality rates for adults passing through turbines will be higher than for juveniles. Several studies have shown mortality rates from 22 to 57% for summer steelhead passing through Kaplan turbines at Foster and Lower Monumental Dams (Wagner and Ingram 1973, Buchanan and Moring 1986, Liscom and Stuehrenberg 1985). The 22 and 41% mortalities observed in 1969 and 1970 by Wagner and Ingram (1973) represented only those fish with observable injuries, indicating direct strike; as such, these estimates are minimums. Theoretical strike calculations by Chet Scott, consulting engineer in the Rock Island Settlement hearing, showed 41 and 49% mortality for 25 and 30-inch fish, respectively (NOAA Hydro Division memorandum, December 5, 1985).

The COE and Battelle Pacific Northwest National Laboratory conducted a turbine passage survival workshop, which included a panel discussion of adult passage (Carlson 2001). Effects on adults associated with passage through turbines can affect upstream migrants of any species that "fallback" through turbines because they overshot their natal tributary or from behavior associated with searching for that stream. It can also affect steelhead kelts that have spawned and are migrating downstream to return to the Pacific Ocean. The topic has two components: what percentage of adults fallback through turbines, and what are the injury and mortality rates associated with this route of passage?

Although the rate of adult fallback at dams has been documented, the proportion that can be attributed to dam operations versus migratory behavior is not clear. A high proportion of fallback behavior is associated with the Bonneville Dam Bradford Island exit during spill. Adult salmon are shoreline oriented and follow the Bradford Island forebay shoreline around to the spillway where they are entrained by spill. However, a substantial number of fish fall back from several miles upstream, and this behavior appears unrelated to dam operations. Mobile tracking of radio-tagged fish has been conducted in the Bonneville First Powerhouse forebay. This information has been modeled in conjunction with physical models of hydraulic conditions and dam operations to further understand the causes of fallback at the Bradford Island fish ladder exit. Fallback over Ice Harbor Dam of fish destined to the upper Columbia River appears more related to searching for the appropriate tributary than dam operations. Similarly, fallback of fall chinook in the Snake River appears related to fish over-shooting the entrance to Lyons Ferry Hatchery.

Despite limited information regarding cause, fall back of adults past dams is a serious issue because the mortality associated with this behavior can be high, especially during periods of no spill. Moreover, increased energetic costs associated with migration delays and re-ascending dams may impact reproductive success. For example, Brown et al. (2002) showed a 62% increase in energetic demand for spring chinook salmon in the tailrace of Bonneville Dam when compared to the forebay, and a 26% increase compared to fishways.

Survival of spring and summer chinook salmon from Ice Harbor Dam to spawning grounds or hatcheries varied between years, and was estimated to be as high as 77% and as low as 54% in 1993 and 1991, respectively. Further studies are required to resolve the variability of these preliminary observations and improve our understanding of losses that occur above Lower Granite Dam.

The potential effects of migration through the hydropower system on adult reproductive success is unknown. Successful reproduction requires a migration of both sexes to the spawning grounds, appropriate lipid reserves to carry out the necessary reproductive behavior (nest building and defense, and spawning), high gamete quality, proper embryonic development, and survival of offspring for the downstream migration. Delays, excessive energy consumption, and exposure to higher water temperatures during the migration are factors that could lead to reduced reproductive function, disease, and low quality and quantity of gametes. A literature review of the effect of temperature on salmonids by McCullough et al.(2001) found that laboratory and field studies show warmer water temperatures (>13-15.6°C) cause a detrimental effect on the size, number and/or fertility of eggs.

Test fish for radiotelemetry studies in the past were selected from the entire population crossing a given dam, without knowing the source, origin, or evolutionary significant unit (ESU) of the fish tagged. This was problematic when using radio-tagged fish to determine inter-dam losses, since the origin of the fish lost between release and upstream sites was unknown. In recent years, the number of PIT-tagged adults returning to the Columbia River has increased and this, along with the development of adult PIT-tag detection systems at key locations, will enable more precise estimates of survival and inter-dam losses for known-source fish.

Adult counting occurs at all mainstem dams to ensure, among other purposes, that fish passage facilities are operating properly. Partial hourly counts are expanded, and little counting occurs during hours of darkness. Counts include all adults passing each dam, and are upwardly biased by any fish that fall back and reascend. The present counting schedule and systems meet this intended purpose. However, additional counts during winter months are now necessary for management of winter steelhead passage at Bonneville Dam and steelhead passage in the lower Snake River. The ISAB noted a number of problems associated with the precision and accuracy of adult counts at mainstem dams, especially if the data are used to make fisheries management decisions (Bisson et al. 1999).

Straying of steelhead into the Deschutes River, OR has been observed during recent radiotelemetry studies. The natal origin of these fish was unknown. The behavior was observed during periods when the water of the Columbia River was warmer than the Deschutes River. Possible causes for this behavior include fish seeking the cooler water, straying behavior associated with transportation, and an evolutionary adaptation that enhances survival. Additional studies of known-source fish will be required to better understand the cause of this observed behavior.

The potential impacts adult fish passage systems have on non-salmonid species is an uncertainty associated with salmonid passage. Concurrent with the decline of salmonid populations, Columbia River Pacific lamprey (*Lampetra tridentata*) populations have also declined. Indigenous peoples from the Pacific coast to the interior Columbia River have harvested adult lamprey for subsistence, religious, and medicinal purposes for many generations (Close et al. 2002). In the Columbia River drainage, adult Pacific lamprey support fisheries that have recently experienced dramatic declines and unprecedented regulation and concern about the status of Pacific lamprey has resulted in a recent petition to list this species under the Endangered Species Act (Moser and Close 2003).

As an anadromous species, lamprey must pass through the same hydropower system as salmonids. However, they have different migration behaviors and lack the physical swimming capabilities of salmon. Passage success studies show that although approximately 90% of the lamprey released downstream from Bonneville Dam from 1997 to 2000 reapproached the dam, less than 50% successfully passed and required a median passage time of 4-6 d (Moser et al. 2002). Radiotelemetry studies also indicated that lamprey had the least success in areas with confusing flows and/or structural obstacles, primarily where gratings exist on the floor of the fishway system, and at the serpentine weirs near the tops of ladders. Additional studies are needed to address whether the hydropower system is impacting lamprey recruitment, homing, and life histories.

White sturgeon *(Acipenser transmontanus)* are an important recreational, commercial, and cultural resource in the Columbia River Basin. However, white sturgeon populations vary considerably in abundance and age structure throughout the Basin (Beamesderfer et al. 1995). The abundance and density of fish is greatest in the unimpounded river downstream from Bonneville Dam and this area supports one of the largest and most productive sturgeon populations in the world. However, the white sturgeon population from the Kootenai River in northern Idaho has been listed as endangered since 1994, and populations in the Snake River downstream from Hells Canyon Dam appear to be persisting but at a lower abundance than prior to impoundment (Devore et al. 1995).

This variation in population status can be attributed to a number of factors including differences in exploitation rates and recruitment success, access to marine food resources, and suitability of hydrologic conditions and available habitats (Beamesderfer et al. 1995, DeVore et al. 1995). In particular, construction and operation of hydroelectric dams on the Columbia and Snake Rivers has directly affected white sturgeon populations in several ways. Spawning habitats are reduced (Parsley and Beckman 1994), upstream and downstream passage is limited , and substantial numbers of juvenile and adult fish can be entrained and killed during dam maintenance activities. White sturgeon seldom ascend the existing fishways at the hydroelectric projects presumably because the fish passage facilities for upstream migrating fish at Columbia River Basin dams were designed primarily for anadromous salmonids (Warren and Beckman 1993).

Little is known about sturgeon downstream passage through dams. Fisheries sampling done by the Oregon and Washington Departments of Fish and Wildlife and angler returns of tagged fish have resulted in several recaptured fish that had moved downstream past one or more dams. North et al. (in press) reports that since 1987, the Oregon Department of Fish and Wildlife has recovered four tagged white sturgeon that passed upstream and 74 fish that passed downstream through one or more dams. Thus, construction of hydroelectric dams on the Columbia and Snake Rivers may restrict movements of white sturgeon to impounded reaches, effectively resulting in a series of individual landlocked populations with potentially reduced genetic diversity (North et al. 1993). Prior to dam construction in the Columbia River Basin, white sturgeon likely responded to seasonal changes in food and habitat availability by ranging extensively between freshwater, estuarine, and marine environments. Because the physiochemical and biotic characteristics of reservoirs vary greatly within the basin, individual impoundments may not contain optimal conditions for all life stages of white sturgeon (Parsley and Beckman 1994, Beamesderfer et al. 1995). Identifying the specific factors currently influencing or limiting white sturgeon movement at dams and improving passage could enhance the productivity of white sturgeon populations.

American shad (*Alosa sapidissima*) are not indigenous to the Columbia River Basin, but this species has successfully exploited the reservoir habitat currently available in the hydropower system. A total of 4.6 million shad passed Bonneville Dam in 2003. A fishery on shad at The Dalles Dam resulted in an increased passage time for chinook salmon as well as an increased rate of fallback (Jepson et al. 2003). Potential biological interactions between shad and salmonids exist but have not been studied. In particular, adult salmonid behavior in fishways may be altered when shad passage peaks occur during late spring and physical crowding in the ladders occurs due to high shad densities. Examinations of fine-scale salmonid behaviors in and around the fishways during these periods are needed to assess potential interspecific interactions.

Adult Passage Conclusions

1. Recent radiotelemetry estimates of adult salmonid survival from Ice Harbor to Lower Granite Dam on the Snake River have been generally well over 90%. Recent PIT-tag estimates of survival from Bonneville Dam on the lower Columbia River to Lower Granite Dam have been over 80% for spring/summer chinook salmon and 70-80% for steelhead. For adult salmonids that do not fall back at dams, estimates of survival range from 3 to 5% higher than for those that do fall back.

2. Delays in dam passage for upstream migrating adult salmonids are associated with high levels of spill ($\geq$40 kcfs), highly fluctuating spill, and high turbidity. Fishway entrance preferences are for deep/wide openings with significant attraction flow. The transition areas between collection channels and ladders are the fishway segments where adult chinook salmon and steelhead are most likely to turn around and exit the fishway.

3. Overall travel times and migration rates of radio- and PIT-tagged adult salmonids from Bonneville Dam to upriver Columbia or Snake River sites vary by species/run, time of year, and environmental conditions. While delay of adult salmonid passage at Columbia and Snake River dams has been documented, recent estimates of travel times and migration rates are similar to times and rates observed during the early development of the FCRPS when there were fewer dams and the Snake River was unimpounded.

4. Fallback rates vary by species/run, environmental conditions, and dam. Higher fallback rates are associated with high river flows and spill, and with adult fishway exit locations in close proximity to spillways. Fallbacks result in an overestimation of adult counts at fish ladder count windows.

5. Powerhouse zero flow operations at night do not appear to affect migrations rates and passage of adult salmonids.

6. For adult salmonids, elevated river water temperatures (>20°C) increase travel times between dams and passage through fishways at dams. Warm water temperatures during the summer, which often exceed 20°C in the Columbia and Snake Rivers, also may reduce reproductive success of salmonids.

7. Although monitoring of adult salmonids for signs of GBD has occurred at Columbia and Snake River dams since 1994 (including periods of very high TDGS), very few signs have been observed. The relationships between TDGS exposure, GBD signs, mortality, and spawning success are not well understood.

8. Estimates of repeat spawning rates for steelhead kelts that migrate downstream through the Snake and Columbia Rivers are low (~2%). While potentially negative effects of the hydrosystem on iteroparity rates have been recognized, the magnitude of the effects on survival and reproductive success are not clearly understood. Higher flows and spill significantly reduce travel and passage times for downstream migrating kelts.

9. Adult survival above the hydrosystem to hatcheries or spawning grounds is variable and estimates from Ice Harbor Dam using radiotelemetry range from 54 to 77%. The effects of passage through the hydrosystem on reproductive success are unknown.

10. The impacts of predation by marine mammals on Columbia River Basin salmon populations are not well understood. In general, very little is known regarding how the existence and operation of the FCRPS may have altered the historical habitat and salmonid consumption rates of marine mammals.

11. Relative to salmonids, upstream passage at Columbia and Snake River dams is poor for adult Pacific lamprey and white sturgeon. American shad have thrived in the hydrosystem habitat but the effects of the biological interactions between adult shad and salmonids (in particular with regard to extremely high fish densities in the fishways during late spring) have not been studied.

REFERENCES

Abernathy, C. S., B. G. Amidan, and G. F. Cada. 2001. Laboratory studies of the effects of pressure and dissolved gas supersaturation on turbine-passed fish. Report by Battelle Pacific National Laboratory to Dept. of Energy, March 2001, 58 p. plus appendices.

Absolon, R. F., E. M. Dawley, and B. P. Sandford. 1999. Changes in gas bubble disease signs and survival of migrating juvenile salmonids experimentally exposed to supersaturated gasses, 1997. Annual report to Bonneville Power Administration P.O. Box 3621, Portland OR 97208-3621. Contract No.: 96-BI-93892: 16p.

Absolon, R. F., B. P. Sandford, and D. B. Dey. 2000a. Post-construction evaluation of the new juvenile bypass system and guidence screen modifications at John Day Dam, 1998. Report to the U.S. Army Corps of Engineers, Contract W66QKZ80354028. 34 p. plus Appendices (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Absolon, R. F., B. P. Sandford, and D. B. Dey. 2000b. Post-construction evaluation of the new juvenile bypass system at John Day Dam, 1999. Report to the U.S. Army Corps of Engineers, Contract W66QKZ80354028, 24 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Absolon, R. F., M. B. Eppard, and B. P. Sandford. 2003. Relative survival of PIT-tagged hatchery chinook salmon through Ice Harbor Dam, 2003. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, 2003 Annual Review, Walla Walla, WA.)

Absolon, R. F., M. B. Eppard, B. P Sandford, G. A Axel, E. E. Hockersmith and J. W. Ferguson. 2003. Effects of turbines operating at two different discharge levels on survival and condition of yearling chinook salmon at McNary Dam, 2002. National Marine Fisheries Service, Northwest Fisheries Science Center. Final Report to U.S. Army Corps of Engineers, Walla Walla District. 20 p.

Absolon, R. F., E. M. Dawley, B. P. Sandford, J. W. Ferguson, and D. A. Brege. 2002. Relative Survival of Juvenile Salmon Passing Through the Spillway at The Dalles Dam, 1997-2000. Report to the U.S. Army Corps of Engineers, Contract MIPR W66QKZ83437725. 58 p. plus appendicies. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Adams, N.S., and D. W. Rondorf. 1999. Migrational characteristics of juvenile chinook salmon in the forebay of Lower Granite Dam relative to the 1998 surface bypass collector tests. Report to U.S. Army Corps of Engineers, Contract E86930151, 166 p. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Adams, N. S. and D. W. Rondorf. 2001. Juvenile Chinook salmon and steelhead passage in the forebay of Lower Granite Dam relative to surface bypass collector and behavioral guidance structure tests. Report prepared for U.S. Army Corps of Engineers, Project # E 86930151. 120p.

Adams, N. S., D. W. Rondorf, E. E. Kofoot. 1997. Migrational characteristics of juvenile spring chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1996 surface bypass collector tests. Report to U.S. Army Corps of Engineers, Contract E86930151, 260 p. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998a. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile chinook salmon. Transactions of the American Fisheries Society 127:128-136.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998b. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Science 55:781-787.

Adams, N. S., D. W. Rondorf, and M. A. Tuell. 1998c. Migrational characteristics of juvenile spring chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1997 surface bypass collector tests. Report to U.S. Army Corps of Engineers, Walla Walla District, Walla Walla. Washington, Contract E86930151, 112 p. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Allen, B., T. L. Liedtke, A. Daniel, J. Begala, M. Salway, and J. Beeman. 2001. Monitoring tailrace egress in the stilling basin, the ice trash sluiceway and the powerhouse of The Dalles Dam, 2000. U.S. Geological Survey final report to U.S. Army Corps of Engineers, Portland District. 62 p.

American Society of Civil Engineers (ASCE). 1995. Guidelines for design of intakes for hydroelectric plants by the Committee on Hydropower Intakes of the Energy Division of the American Society of Civil Engineers, p. 215-283.

Anglea, S. M. 1999. Fixed location hydroacoustic evaluation of the prototype surface bypass structures at Lower Granite Dam in 1999. Preliminary Analyses to the U.S. Army Corps of Engineers, Contract DACW68-96-D-0002, 24 p. (Available from Battelle's Northwest Division, P.O. Box 999, Richland, WA 99352.)

Anglea, S. M., R. L. Johnson, E. A. Kudera, and J. R. Skalski. 1999. Fish passage at the prototype surface bypass/collector and behavioral guidance structure at Lower Granite Dam in spring, 1999. *In* Abstracts, Anadromous Fish Evaluations Program 1999 Annual Research Review, November 1999. (Available fromU.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Anglea, S. M., R. L. Johnson, E. A. Kudera, and J. R. Skalski. 2000. Fixed location hydroacoustic evaluation of the prototype surface bypass and collector at Lower Granite Dam in 2000. *In* Abstracts, Anadromous Fish Evaluations Program 1999 Annual Research Review, November 2000. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Anglea, S., T. Poe, and A. Giorgi. 2001a. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at John Day Dam (1980-2000). Report to the U.S. Army Corps of Engineers, Portland District, Portland OR. 98 p plus Appendix.

Anglea, S. M., M. A. Simmons, J. P. Duncan, C. A. Mckinstry, R. L. Johnson, S. L. Thorsten, M. A. Chamness, E. A. Kudera, and J. R. Skalski. 2001b. Fixed-location hydroacoustic evaluatioin of the prototype surface bypass and collector at Lower Granite Dam in 2000. Report to the U. S. Army Corps of Engineers, Contract DACW68-96-D-002, Delivery Order 0013 pp. 1.2-7.1. (Available from Battelle Northwest, P.O. Box 999, Richland WA 99352).

Angelea, S. M., G. E. Johnson, T. O. Wik, L. A. Reese, and A. E. Giorgi. 2002. Development of the surface bypass and collector for juvenile salmon and steelhead at lower Granite Dam 1994-2000. Report to U.S. Army Corps of Engineers, Contract DACW68-96-D-0016. Battelle Northwest and BioAnalysts, Inc. pp. 6.1-8.8, plus Appendices.

Anglea, S. M., K. D. Ham, G. E. Johnson, M. A. Simmons, C. S. Simmons, E. Kudeera, and J. Skalski. 2003. Hydroacoustic evaluation of the removable spillway weir at Lower Granite Dam in 2002. Report to the U. S. Army Corps of Engineers, Contract DACW68-96-D-002, Delivery Order 0001 pp. 1.1-7.2. (Available from Battelle Northwest, P.O. Box 999, Richland WA 99352.)

Anderson, J., A. Giorgi, J. McKern, H. Schaller, L. Krasnow, S. G. Smith, C. Toole, E. Weber, J. Williams, P. Wilson. 1998. Fish guidance efficiency (FGE) estimates for yearling chinook salmon at lower Snake and Columbia River dams; Draft #5 dated 1/29/98. Plan for Analyzing and Testing Hypothesis (PATH) Hydro Work Group, Data Subcommittee Draft Report.

Anonymous. 1996. Acoustic evaluation of fish guidance efficiency for Lower Granite, Little Goose, and McNary Dam, 1995. 13 p. plus Appendix. Final report to U. S. Army Corps of Engineers, Contract DACW68-95-C-0027. (Available from U. S. Army Corps of Engineers, Walla Walla District, Walla Walla WA 99362.)

Axel, G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford. In prep. a. Fish passage and survival at McNary Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford. In prep. b. Passage and survival of hatchery yearling chinook salmon at McNary Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford, S. G. Smith, and D. B. Dey. 2003. Passage behavior and survival of hatchery yearling chinook salmon passing Ice Harbor and McNary Dams during a low flow year, 2001. Report to the U.S. Army Corps of Engineers, Contract W68SBV92844866. 37 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA. 98112-2097.)

Backman, T. W. H., and A. F. Evans. 2002. Gas bubble trauma Incidence in adult salmonids in the Columbia River Basin. N. Am. Jour. Fish. Manage. 22:579-584.

Backman, T. W. H., A. F. Evans, and M. A. Hawbecker. 1998. 1998 Annual Report: Symptoms of gas bubble trauma induced in Salmon (*Oncorhynchus* spp.) by total dissolved gas supersaturation of the Snake and Columbia Rivers, USA. Annual report to Bonneville Power administration, Contract No. 95BI39861, 51P. (Available from Columbia River Inter-Tribal Fish Commission, 729 NE Oregon, Suite 200, Portland, OR. 97235).

Barton, A. B., and C. B. Schreck. 1987a. Influence of acclimation temperature on interrenal and carbohydrate stress response in juvenile chinook salmon (*Oncorhyncus tshawytscha*). Aquaculture 62:299-310.

Barton, A. B., and C. B. Schreck. 1987b. Metabolic cost of acute physical stress in juvenile steelhead. Trans. Am. Fish. Soc. 116:257-263

Barton, A. B., C. B. Schreck, and L. A. Sigismondi. 1986. Multiple acute disturbances evoke cumulative physiological stress responses in juvenile chinook salmon. Trans. Am. Fish. Soc. 115:245-251.

Baxter, R., J. Bailey, S. Moyers, and S. Rapp. 1999. Annual report for 1998; Smolt collection, transportation, and bypass at Little Goose Dam on the Snake River, Washington. 48 p plus Appendix. (Available from U.S. Army Corps of Engineers, Walla Walla District, 201 N. Third St., Walla Walla, WA 99362-1876.)

Beamesderfer, R.C., and B.E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:439-447.

Beamesderfer, R.C.P., T.A. Rien, and A.A. Nigro. 1995. Differences in the dynamics and potential production of impounded and unimpounded white sturgeon populations in the lower Columbia River. Transactions of the American Fisheries Society 124:857-872.

Beeman, J. W., P. V. Haner, T. C. Robinson, and A. G. Maule. 1998. Vertical and horizontal distribution of individual juvenile salmonids bsed on radio telemetry. U.S. Geological Survey, Biological Resources Division, Columbia River Research Laboratory, Cook, WA.

Beeman, J.W., H.C. Hansel, P.V. Haner, K. Daniel, and J. Hardiman. 2002a. Estimates of fish and spill passage efficiency of radio-tagged subyearling chinook salmon at John Day Dam during the summer of 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 68 p.

Beeman, J.W., H.C. Hansel, P.V. Haner, and J. Hardiman. 2000a. Estimates of fish-, spill-, and sluiceway-passage efficiencies of radio-tagged juvenile steelhead and yearling chinook salmon at The Dalles Dam, 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 44 p. plus Appendix.

Beeman, J.W., H.C. Hansel, P.V. Haner, and J. Hardiman. 2000b. Estimates of fish-, spill-, and sluiceway-passage efficiencies of radio-tagged fall chinook salmon at The Dalles Dam, 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 43 p. plus Appendix.

Beeman, J.W., H.C. Hansel, P.V. Haner, and J. Hardiman. 2001. Estimates of fish and spill passage efficiency of radio-tagged juvenile steelhead and yearling chinook salmon at John Day Dam during the spring of 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 70 p.

Beeman, J.W., H.C. Hansel, P.V. Haner, S. Juhnke, L. Dingmon, L. Kelly, J. Phelps, and B. Hausmann. 2002b. Estimates of fish and spill passage efficiency of radio-tagged juvenile salmonids relative to 12 and 24-h spill discharge at John Day Dam, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, 2002 Annual Review, Portland, OR.

Beeman, J.W., Juhnke, S., Daniel, K., Daniel, and P.V. Haner. 2003. Estimates of the stilling basin residence time and lateral distribution of passage of juvenile Chinook salmon passing through the spillway of The Dalles Dam, 2001. Prepared for U.S. Army Corps of Engineers, Portland District, Contract No. W66QKZ10805878. 37p.

Beeman, J.W., and seven coauthors. 2002. Estimates of fish passage efficiency of radio-tagged juvenile salmonids relative to operation of J-Design intake occlusion plates at The Dalles Dam, 2002. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Annual Review, 2002, Portland, OR.

Beeman, J. W., T. C. Robinson, P. V. Haner, S. P. Vanderkooi, and A. G. Maule. 1999. Gas bubble monitoring and research of juvenile salmonids. Annual Progress Report of U.S. Geological Survey, Biological Resources Division, Columbia River Research Laboratory, Cook, WA, to Bonneville Power Administration, Portland, OR.

Beiningen, K. T., and W. J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Trans. Am. Fish. Soc. 99:664-671.

Bell, M.C. 1981. Recommendation for turbine generator loadings and blade gate relationships for the best survival of juvenile migrants at the eight Columbia Basin Dams operated by the Corps of Engineers. Letter to North Pacific Division, Portland, Oregon.

Bell, Milo C. 1991. Fisheries handbook of engineering requirements and biological criteria. Repport to U.S. Army Corps of Engineers, Portland, OR. (Available from U.S. Army Corps of Engineers, Portland District, Portland, OR.)

Bell, M. C., A. C. DeLacy, and G. J. Paulik. 1967. A compendium on the success of passage of small fish through turbines. Report prepared for the North Pacific Division of the U.S. Army Corps of Engineers. Portland, Oregon.

Bell, M. C., A. C. Delacy, G. J. Paulik, K. J. Bruya, and C. T. Scott. 1981. Updated compendium on the success of passage of small fish through turbines. Report to U.S. Army Corps of Engineers, Contract DACW-6P-76-C-0254, 25 p. plus Appendixes.

Bickford, S. A. and J. R. Skalski. 2000. Reanalysis and interpretation of 25 years of Snake-Columbia River juvenile salmonid survival studies. N. Am. J. Fish. Manage. 20:53-68.

Biological Monitoring Inspection Team. 1995. Research priorities related to gas bubble monitoring needs in the Columbia River Basin. Report to National Marine Fisheries Service/EPA Gas Bubble Disease Technical Work Group.

BioSonics Inc. 1996a. Hydroacoustic evaluation and studies at The Dalles Dam, spring/summer 1996. Volume 1 - Fish Passage. Report to U.S. Army Corps of Engineers, 59 p. plus Appendixes. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

BioSonics, Inc. 1996b. Acoustic evaluation of the surface bypass and collection system at Ice Harbor Dam in 1995. Final report prepared by BioSonics for U.S. Army Corps of Engineers. Contract No.DACW68-95-C-0027, Walla Walla, WA.

BioSonics Inc. 1997. Hydroacoustic evaluation and studies at The Dalles Dam, spring/summer 1996. Volume 1 - Fish Passage. Report to U.S. Army Corps of Engineers, Portland District, 64 p. plus Appendixes. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

BioSonics Inc. 1998. Hydroacoustic evaluation and studies at Bonneville Dam, spring/summer 1997. Volume 1 - Fish Passage. Report to U.S. Army Corps of Engineers. 118 p. plus Appendixes. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

BioSonics Inc. 1999a. Hydroacoustic study at John Day Dam, 1997. Volume 1 - Fish Passage. Report to U.S. Army Corps of Engineers, Contract DACW57-96-D-005, 173 p. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

BioSonics, Inc. 1999b. Hydroacoustic study at John Day Dam, 1998. Report to U.S. Army Corps of Engineers, Contract DACW57-96-D-005. 57 p. plus Appendixes. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

Biosonics Inc. 1999c. Hydroacoustic evaluation and studies at The Dalles Dam, spring/summer 1998. Report to U.S. Army Corps of Engineers, Contract DACW57-96-D-0005, 60 pages plus Appendixes. (Available from Biosonics, Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

Bisson, P. A, C. C. Coutant, D. Goodman, J. A. Lichatowich, W. Liss, L. McDonald, P. R. Mundy, B. E. Riddell, R. R. Whitney, and R. N. Williams. 1999. Report of the Independent Scientific Advisory Board, Part III, Review of the U.S. Army Corps of Engineers' Capital Construction Program. ISAB Report 99-4. 58 p. (Available from Northwest Power Planning Council, 851 S.W. Sixth Avenue, Suite 1100, Portland, OR 97204.)

Bjornn, T. C., J. P. Hunt, P. J. Keniry, and R. R. Ringe. 1998d. Turbine priority and its effects on passage of steelhead at Snake River dams. Part IV. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries. 73 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., J. P. Hunt, P. J. Keniry, and R. R. Ringe. 1998f. Movements of steelhead in fishways relation to transition pools. Part V. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries. 44 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., J. P. Hunt, K. R. Tolotti, P. J. Keniry, and R. R. Ringe. 1995. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries - 1993. Technical report 95-1 to U.S. Army Corps of Engineers, 212 p. plus Appendix. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., J. P. Hunt, K. R. Tolotti, P. J. Keniry, and R. R. Ringe. 1998b. Entrances used and passage through fishways for adult chinook salmon and steelhead. Part III. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries, 99 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., J. P. Hunt, K. R. Tolotti, P. J. Keniry, and R. R. Ringe. 1998g. Effects of zero versus normal flow at night on passage of steelhead in summer and fall. Part VII. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries, 62 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., M. L. Keefer, C. A. Peery, K. R. Tolotti, R. R. Ringe, and L. C. Stuehrenburg. 1998a. Adult chinook and sockeye salmon, and steelhead fallback rates at Bonneville Dam - 1996, 1997, and 1998. Report to U.S. Army Corps of Engineers and Bonneville Power Administration, Project MPE-P-95-1, 73 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T.C., M .L. Keefer, C. A. Peery, K. R. Tolotti, R. R. Ringe, P. J. Keniry, and L. C. Stuehrenberg. 2000. Migration of adult spring and summer Chinook salmon past Columbia and Snake River dams, through reservoirs, and distribution into tributaries, 1996. U.S. Army Corps of Engineers, Technical Report 2000-5, 154 p. (Available online at http://www.nwp.usace.army.mil/pm/e/afep_reports.htm).

Bjornn, T. C., M. L. Keefer, and L. C. Stuehrenburg. 1999. Behavior and survival of adultchinook salmon that migrate past dams and into tributaries in the Columbia River drainage as assessed with radio telemetry. *In* Proceedings of the Fifteenth International Symposium on Biotelemetry, Juneau, Alaska.

Bjornn, T. C., and C. A. Peery. 1992. A review of literature related to movements of adult salmon and steelhead past dams and through reservoirs in the lower Snake River. U.S. Army Corps of Engineers, Technical Report 92-1, 80 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., C. A. Peery, K. R. Tolotti, M. A. Jepsen, and L. C. Stuehnrenberg. 1998e. Evaluation of running turbine 1 at maximum capacity on passage of adult salmon and steelhead at John Day Dam - 1987. Technical Report 98-3 to U.S. Army Corps of Engineers, 23 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Bjornn, T. C., K. R. Tolotti, J. P. Hunt, P. J. Keniry, R. R. Ringe, and C. A. Peery. 1998c. Passage of chinook salmon through lower Snake River and distribution into the tributaries, 1991-1993. Part 1. Report to U.S. Army Corps of Engineers, 95 p. (Available from Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID 83843.)

Boggs, C. T., M. L. Keefer, C. A. Peery, T. C. Bjornn, L. C. Stuehrenberg. In review. Fallback, reascension, and adjusted fishway escapement estimates for adult chinook salmon and steelhead at Columbia and Snake River dams. Trans. Am. Fish. Soc.

Boggs, C. T., and C. Peery. 2003. Abstract: Abundance, timing, migration rates and survival of Snake River steelhead kelts in 2003. Anadromous Fish Evaluation Program Annual Review, 2003. U.S. Army Corps of Engineers, Walla Walla District.

Brege, D. A., R. F. Absolon, and R. J. Graves. 1996. Seasonal and diel passage of juvenile salmonids at John Day Dam on the Columbia River. N. Am. J. Fish. Manage. 16:659-665.

Brege, D. A., R. F. Absolon, B. P. Sandford, and D. B. Dey. 1994. Studies to determine the effectiveness of extended traveling screens and extended bar screens at The Dalles Dam, 1993. Report to U.S. Army Corps of Engineers, Contract E96930030, 26 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.) .

Brege, D. A., R. F. Absolon, B. P. Sandford, and D. B. Dey. 1997a. Studies to evaluate the effectiveness of extended-length screens at John Day Dam, 1996. Report to U.S. Army Corps of Engineers, Contract E96960028, 22 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., R. F. Absolon, B. P. Sandford, and D. B. Dey. 1997b. Studies to evaluate the effectiveness of extended-length screens at the Dalles Dam, 1995. Report to U.S. Army Corps of Engineers, Contract E969630030, 24 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., R. F. Absolon, B. P. Sandford, and D. B. Dey. 1998. Studies to evaluate the effectiveness of vertical barrier screens and outlet flow-control devices at McNary Dam, 1997. Report to U.S. Army Corps of Engineers, Contract E86970083, 19 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., S. J. Grabowski, W. D. Muir, S. R. Hirtzel, S. J. Mazur, and B. P. Sandford. 1992. Studies to determine the effectiveness of extended traveling screens and extended bar screens at McNary Dam, 1991. Report to U.S. Army Corps of Engineers, Contract E86910060, 32 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., D. R. Miller, and R. D. Ledgerwood. 1987. Evaluation of the rehabilitated juvenile salmonid collection and passage system at John Day Dam - 1986. Report to U.S. Army Corps of Engineers, Contract DACW57-86-F-0245, 30 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., W. T. Norman, G. A. Swan, and J. G. Williams. 1988. Research at McNary Dam to improve fish guiding efficiency of yearling and subyearling chinook salmon - 1987. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 22 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., G. A. Swan, and J. G. Williams. 1988. Fish guidance efficiency studies at Ice Harbor Dam, 1987. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 14 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Brege, D. A., J. W. Ferguson, R. F. Absolon, and B. P. Sandford. 2001. Evaluation of extended-length bypass screens at John Day Dam, 1999. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ90392273, 21 p. plus Appendices. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA. 98112-2039.)

Brege, D. A., R. F. Absolon, B. P. Sandford, and J. W. Ferguson. 2004. Evaluation of extended-length bar screens at John Day Dam, 2002. Report to the U.S. Army Corps of Engineers, Portland District, Contract W66QKZ90392273, 30 p. plus Appendices. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA. 98112-2039.)

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. Journal of the Fisheries Research Board of Canada 9:265-322.

Brett, J. R. and Alderdice D. F. 1958. Research on guiding young salmon at two British Columbia field stations. Fisheries Research Board of Canada Bulletin. Bulletin Number 117. 75 p.

Brown, R. S., D .R. Geist, and M. G. Mesa. 2002. The use of electromyogram (EMG) telemetry to assess swimming activity and energy use of adult spring Chinook salmon migrating through the tailraces, fishways, and forebays of Bonneville Dam, 2000 and 2001. Report to U.S. Army Corps of Engineers, Portland District, Portland, OR, Contract Number DE-AC06 76RLO1830, 94 p. (Available online at http://www.nwp.usace.army.mil/pm/e/afep_reports.htm).

Buchanan, D. V., and J. R. Moring, 1986. Management problems with recycling of adult summer steelhead trout at Foster Reservoir, Oregon. Fish Culture In Fisheries Management, Proceedings of a Symposium on The Role of Fish Culture in Fisheries Management at Lake Ozark, MO, March 31-April 3, 1985, Fish Culture Section and Fisheries Management Section of the American Fisheries Society, Bethesda, MD, 1986. 10 p.

Cada, G., C. Coutant, and R. R. Whitney. 1997. Development of biological criteria for the design of advanced hydropower turbines. Report to the US Department of Energy Advanced Hydropower Turbine System Program. Idaho Falls, ID: 1997.

Carlson, T. J. 1995. Non-intrusive/non-destructive detection and quantification of gas bubbles in fish. Abstract to U.S. Army Corps of Engineers. Portland, OR. 1 p.

Carlson, T. J. 2001. Proceedings of the turbine fish passage survival workshop held in Portland, Oregon, June 14-15, 2000. (Available from U.S. Army Corps of Engineers, Portland, OR.)

Carlson, T. J., and J. P. Duncan. 2003a. Characterization of the McNary Dam turbine fish passage environment, April 2002. Report by Battelle Pacific National Laboratory to U.S. Army Corps of Engineers, Walla Walla District.

Carlson, T. J., and J. P. Duncan. 2003b. Characterization of the Ice Harbor spill environment. *In* Abstracts, Anadromous Fish Evaluations Program 2003 Annual Research Review, November 2003. (Available fromU.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Carlson, T. J., M. A.Weiland, V. K. Sutton, A. R. Wirtz, M. Macaulay, and J. R. Skalski. 2002. Ultrasonic 3-D tracking of fish and drogues passing through a Kaplan turbine intake at McNary Dam, 1999 & 2000. Report by Battelle Pacific National Laboratory to U.S. Army Corps of Engineers, Walla Walla District. 30 p. plus appendices.

Cash, K. M., T. W. Hatton, E. C. Jones, R. J. Magie, K. C, Mayer, N. M. Swyers, N. S. Adams, and D. W. Rondorf. 2003. Three-dimensional fish tracking to evaluate the removable spillway weir at Lower Granite Dam during 2002. Report to the U.S. Army Corps of Engineers, Project No. W68SV00104592. 80 p. (Available from U.S. Geological Survey, Cook, WA 98605.)

Christensen, P. J., and R. G. Wielick. 1995. Attraction flow - A fish bypass alternative. Proceedings of the American Society of Civil Engineers Waterpower Conference, 1995.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific lamprey. Fisheries 27:19-25.

Congleton, J. L., W. J. Lavoie, C. B. Schreck, and L. E. Davis. 2000. Stress indices in migrating juvenile chinook salmon and steelhead of wild and hatchery origin before and after barge transportation. Transactions of the American Fisheries Society 129 (4): 946-961.

Congleton, J. L., T. C. Bjornn, B. H. Burton, B. D. Watson, J. I. Irving, and R. R. Ringe. 1984. Effects of handling and crowding on the stress response and viability of chinook salmon parr and smolts. Report to Bonneville Power Administration, Contract DE-AC79-83BP11196. 67 p. (Available from Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, OR 97208.)

Congleton, J. L., W. J. LaVoie, C. B. Schreck, L. E. Davis, H. Lorz, M. Beck, D. G. Elliot, R. J. Pascho, D. M. Chase, C. L. McKibbin, and L. J. Applegate. 1999. Evaluation of procedures for collection, bypass, and downstream passage of outmigrating salmonids. Report to U.S. Army Corps of Engineers, Contract MPE-96-10, 36 p. plus Appendixes.

Congleton, J. L., and E. J. Wagner. 1988. Effects of light intensity on plasma cortisol concentration in migrating smolts of chinook salmon and steelhead held in tanks or raceways and after passage through experimental flumes. Trans. Am. Fish. Soc. 117:385-393.

Congleton, J. L., E. J. Wagner, and R. R. Ringe. 1988. Evaluation of fishery designs for downstream passage of spring chinook salmon and steelhead trout smolts, 1987. Report to Bonneville Power Administration, Contract DE-A179-86BP64234, 30 p. plus Appendixes (Available from Idaho Cooperative Fishery Unit, Dept. of Fish and Wildlife Resources, College of Forestry, University of Idaho, Moscow, ID 83842.)

Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2003a. Migrational behavior and seaward movement of wild subyearling fall chinook salmon in the Snake River. N. Am. J. Fish. Manage. 23:414-430.

Connor, W. P., H. L. Burge, J. R. Yearsley, and T. C. Bjornn. 2003b. Influence of flow and temperature on survival of wild subyearling fall chinook salmon in the Snake River. N. Am. J. Fish. Manage. 23:362-375.

Connor, W. P., H. L. Burge, R. Waitt and T. C. Bjornn. 2002. Juvenile life history of wild fall chinook salmon in the Snake and Clearwater Rivers. N. Am. J. Fish. Manage. 22:703-712.

Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2000. Forecasting survival and passage of migratory juvenile salmonids. N. Am. J. Fish. Manage. 20:651-660.

Connor, W. P., H. L. Burge, and D. H. Bennett. 1998. Detection of PIT-tagged subyearling chinook salmon at a Snake River dam: implications for summer flow augmentation. N. Am. J. Fish. Manage. 18:530-536.

Cook, C. B., M. C. Richmond, A. M. Coleman, C. L. Rakowski, S. P. Titzler, and M. D. Bleich. 2003. Numerically simulating the hydrodynamic and water quality environment for migrating salmon in the lower Snake River. Bonneville Power Administration. Available http://www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/DOWNSTRM/D00000652-12.pdf (Accessed October 2003).

Counihan, T. D., K. J. Felton, and J. H. Petersen. 2002. Survival estimates of migrant juvenile salmonids in the Columbia River from John Day Dam through Bonneville Dam using radio-telemetry, 2000. Annual report of research, U.S. Army Corps of Engineers, Portland District, Portland, OR, USA, Contract W66QKZ00402095, W66QKZ00391980, and W66QKZ00381936, 113 p.

Counihan, T. D., K. J. Felton, G. Holmberg, J. H. Petersen. 2003a. Survival estimates of migrant juvenile salmonids in the Columbia River through Bonneville Dam using radio-telemetry, 2002. U.S. Geological Survey draft final report to U.S. Army Corps of Engineers, Portland District. 34 p. plus appendix.

Counihan, T. D., K. J. Huskey, J. H. Petersen. 2001. Survival estimates of migrant juvenile salmonids in the Columbia River from John Day Dam through Bonneville Dam using radio-telemetry. Annual report of research for 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 121 p.

Counihan, T. D, Holmberg, Walker, and J. M. Hardiman. 2003b. Survival estimates of migrant juvenile salmonids in the Columbia River through John Day Dam using radio-telemetry, 2003. Draft Report Prepared for the Portland District of the U.S. Army Corps of Engineers. Portland, Oregon.

Coutant, C. C. 1999. Perspectives on temperature in the Pacific Northwest's fresh waters. PRNL/TM-1999/44. Prepared for the U.S. Environmental Protection Agency by Environmental Sciences Division, Oak Ridge National Laboratory, Contract DE-AC-05-96OR22464.

Coutant, C. C. and R. R. Whitney. 2000. Fish behavior in relation to passage through hydropower turbines: a review. Trans. Am. Fish. Soc. 129:351-380.

Cramer, S. P. 1996a. Seasonal Changes in survival of yearling chinook smolts emigrating through the Snake River in 1995 as estimated from detections of PIT tags. 84 p. Prepared for Direct Services Industries, 825 NE Multnomah St, Portland, OR.

Cramer, S. P. 1996b. Seasonal changes during 1996 in survival of yearling chinook smolts through the Snake River as estimated from detections of PIT tags. 18 p. Prepared for Direct Services Industries, 825 NE Multnomah St, Portland, OR.

Dauble, D. D., T. P. Hanrahan, D. R. Geist, and M. J. Parsley. 2003. Impacts of the Columbia River hydroelectric system on main-stem habitats of fall chinook salmon. N. Am. J. Fish. Manage. 23:641-659.

Dauble, D. D., S. M. Anglea, and G. E. Johnson. 1999. Surface Flow Bypass Development in the Columbia and Snake Rivers and Implications to Lower Granite Dam. Report to U.S. Army Corps of Engineers, Contract DACW68-96-D-0002, 79 p. plus Appendix. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Dauble, D. D., and R. P. Mueller. 1993. Factors affecting the survival of upstream migrant adult salmonids in the Columbia Basin. Recovery issues for threatened and endangered Snake River salmon. Report No. 93-026. Report to Bonneville Power Administration, Portland, OR. 72 p.(Available from Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, OR 97208.)

Dawley, E. M. 1986. Effect of 1985-86 levels of dissolved gas on salmonids in the Columbia River. Report to U.S. Army Corps of Engineers, Contract DACW57-85-F-0623, 31 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

Dawley, E. M., R. Absolon, and C. Ebel. 1999b. Relative survival of juvenile salmon passing through the spillway and ice and trash sluiceway of The Dalles Dam. Final research proposal to U.S. Army Corps of Engineers for FY2000, 17 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

Dawley, E. M., T. Blahm, G. Snyder, and W. Ebel. 1975. Studies on effects of supersaturation of dissolved gases on fish. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.

Dawley, E. M., L. G. Gilbreath, R. F. Absolon, B. P. Sandford, and J. W. Ferguson. 1999a. Relative survival of juvenile salmon passing through the spillway and ice and trash sluiceway of The Dalles Dam, 1998. Report to the U.S. Army Corps of Engineers, Contract MIPR E96970020 & W66QKZ82167243 & W66QKZ83437725. 32 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Dawley, E. M., L. G. Gilbreath, R. F. Absolon, B. P. Sandford, and J. W. Ferguson. 2000a. Relative survival of juvenile salmon passing through the spillway and ice and trash sluiceway of The Dalles Dam, 1998. Report to the U.S. Army Corps of Engineers, Contract MIPR E96970020 & W66QKZ82167243 & W66QKZ83437725. 47 p. plus appendicies. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Dawley, E. M., C. J. Ebel, R. F. Absolon, B. P. Sandford, and J. W. Ferguson. 2000b. Relative Survival of Juvenile Salmon Passing Through the Spillway at The Dalles Dam, 1999. Report to the U.S. Army Corps of Engineers, Contract MIPR W66QKZ83437725. 42 p. plus appendicies. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Dawley, E. M., L. G. Gilbreath, and R. D. Ledgerwood. 1988. Evaluation of juvenile salmonid survival through the second powerhouse turbines and downstream migrant bypass system at Bonneville Dam, 1987. Report to the U.S. Army Corps of Engineers, Contract DACW57-87-F-0323, 36 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Dawley, E. M., L. G. Gilbreath, R. D. Ledgerwood, P. J. Bentley, and B. P. Sandford. 1998a. Effects of bypass system passage at Bonneville Dam Second Powerhouse on downstream migrant salmon and steelhead; direct capture assessment, 1990-1992. Report to the U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 53 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Dawley, E. M., L. G. Gilbreath, R. D. Ledgerwood., P. J. Bentley, B. P. Sandford, and M. H. Schiewe. 1989. Survival of subyearling chinook salmon which have passed through the turbines, bypass system, and tailrace basin of Bonneville Dam Second Powerhouse, 1988. Report to the U.S. Army Corps of Engineers, Contract DACW57-87-F-0323, 43 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Dawley, E. M., L. G. Gilbreath, E. P. Nunnallee, and B. P. Sandford. 1998b. Relative survival of juvenile salmon passing through the spillway of The Dalles Dam, 1997. Report to the U.S. Army Corps of Engineers, Contract E96970020, 26 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

DeVore, J.D., B.W. James, C.A. Tracey, and D.A. Hale. 1995. Dynamics and potential production of white sturgeon in the unimpounded lower Columbia River. Transactions of the American fisheries Society 124:845-856.

Dresser, T. J., and R. J. Stansell. 1998. Adult salmonid jump behavior research in the John Day Dam south ladder, Columbia River, 1997. U.S. Army Corps of Engineers, Portland, OR. 25 p.

Duran, I. N., T. L. Liedtke, L. S. Brown, and J. Beeman. 2002. Monitoring tailrace egress in the stilling basin and the bypass system outfall at John Day Dam, 2000. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 72 p.

Ebel, W. J. 1969. Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. Fish. Bull., U.S. 68:1-11.

Ebel, W. J., E. M. Dawley, and B. H. Monk. 1971. Thermal tolerance of juvenile pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fish. Bull., 69:833-843.

Ebel, W. J., H. L. Raymond, G. E. Monan, W. E. Farr, and G. K. Tanonaka. 1975. Effects of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia Rivers. Processed Report, 111 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

Eicher Associates Inc. 1987. Turbine-related fish mortality: review and evaluation of studies. Report to the Electric Power Research Institute, Palo Alto, CA. 93 p. plus Appendixes.

Elliott, D. G., and R. J. Pascho. 1991. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Report to U.S. Army Corps of Engineers, Contract E86880047, 107 p. plus Appendix.

Elston, Ralph. 1996. Investigation of head burns in adult salmonids. Phase 1: Examination of fish at Lower Granite Dam, July 2, 1996. Report to Bonneville Power Administration, Portland, OR, Contract 96AP95973, 12 p. (Available from Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, OR 97208.)

ENSR, Harza, Inca Engineers Inc, and Cornforth Consultants. 1998. Final Report: Bonneville First Powerhouse juvenile fish surface bypass high flow dewatering facility and outfall alternatives study. Prepared for U.S. Army Corps of Engineers, Contract No.DACW57-97-D-0007.

Eppard, M. B., G. A. Axel, B. P. Sandford, and D. B. Dey. 2000. Effects of spill on the passage of hatchery yearling chinook salmon at Ice Harbor Dam, 1999. Report to U.S. Army Corps of Engineers, Delivery Order W66QKZ91521282, 29 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Eppard, M. B., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002a. Spillway survival for hatchery yearling and subyearling chinook salmon passing Ice Harbor Dam, 2000. Report to U.S. Army Corps of Engineers, Contract W68SBV92844866, 56 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Eppard, M. B., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002b. Ice Harbor Dam spillway survival and migrational characteristics of juvenile chinook salmon through McNary Dam, 2002. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, 2002 Annual Review, Portland, OR.

Eppard, E. M., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2003. Migrational behavior and survival of radio-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 2003. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, 2003 Annual Review, Walla Walla, WA.)

Evans, A. F., and R. E. Beaty. 2000. Identification and enumeration of steelhead (*Oncorhynchus mykiss*) kelts at Little Goose Dam juvenile bypass separator, 1999. Report from Columbia River Inter-Tribal Fish Commission, Portland OR, to U.S. Army Corps of Engineers, Walla Walla District.

Evans, A. F., and R. E. Beaty. 2001. Identification and enumeration of steelhead (*Oncorhynchus mykiss*) kelts in the juvenile collection systems of Lower Granite and Little Goose Dams, 2000. Report from Columbia River Inter-Tribal Fish Commission, Portland OR, to U.S. Army Corps of Engineers, Walla Walla District.

Evans, S. D., J. M. Plumb, A. C. Braatz, K. S. Gates, N. S. Adams, and D. W. Rondorf. 2001a. Passage behavior of radio-tagged yearling chinook salmon and steelhead at Bonneville Dam associated with the surface bypass program, 2000. Report of Research to U.S. Army Corps of Engineers, Portland District, Portland, OR. (Available from U.S. Geological Survey.) 40 p.

Evans, S. D.,C. D. Smith, N. S. Adams, and D. W. Rondorf. 2001b. Passage behavior of radio-tagged yearling chinook salmon and steelhead at Bonneville Dam associated with the surface bypass program, 2001. Report of Research to U.S. Army Corps of Engineers, Portland District, Portland, OR. U.S. Geological Survey. 31 p.

Evans, S. D.,L. S. Wright, C. D. Smith, R. E. Wardell, N. S. Adams, and D. W. Rondorf. 2002. Passage behavior of radio-tagged yearling chinook salmon and steelhead at Bonneville Dam, 2002. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, 2002 Annual Review, Portland, OR.

Faler, M. P., L. Miller, and K. Welke. 1988. Effects of variation in flow on distribution of northern squawfish in the Columbia River below McNary Dam. N. Am. J. Fish. Manage. 8:30-35.

Ferguson, J. W. 1993. Improving fish survival through turbines. Hydro Review, April 1993. pp. 54-61.

Ferguson, J. W., R. F. Absolon, T. J. Carlson, B. P. Sandford. In prep. Condition and Survival of Juvenile Pacific Salmon Passing Through Kaplan Turbines at McNary Dam on the Columbia River. (Available from NOAA Fisheries Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112)

Fidler, L. E., and S. B. Miller. 1993. British Columbia water quality guidelines for dissolved gas supersaturation. Report to B.C. Ministry of Environment, Canada Department of Fisheries and Oceans, 94 p. plus Appendix. (Available from B.C. Ministry of Environment, Water Quality Branch, Water Management Division, 765 Broughton St., Victoria, B.C.)

Fish Passage Center (FPC). 1995. Summary of the 1995 spring and summer juvenile passage season. 32 p. Fish Passage Center, Portland, Oregon.

Franke, G. F., and nine co-authors. 1997. Development of environmentally advanced hydro turbine design concepts. Report to U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID.

Gadomski, D. M., M. G. Mesa, and T. M. Olson. 1994. Vulnerability to predation and physiological stress of experimentally descaled juvenile chinook salmon (*Oncorhynchus tshawytscha*). Environ. Biol. Fishes 39:191-194.

GBD Panel. 1996. Summary report by the panel on gas bubble disease. 33 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., W. E. Farr, and C. W. Long. 1985. Underwater separation of juvenile salmonids by size. Mar. Fish. Rev. 47(3):38-42.

Gessel, M. H., L. G. Gilbreath, W. D. Muir, R. F. Krcma. 1986. Evaluation of the juvenile collection and bypass systems at Bonneville Dam, 1985. Report to U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 63 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., W. D. Muir, B. P. Sandford, and D. B. Dey. 1993. Evaluation of the new juvenile salmonid bypass system at Lower Monumental Dam, 1992. Report to U.S. Army Corps of Engineers, Contract E86920053, 20 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., B. P. Sandford, and D. B. Dey. 1995. Studies to evaluate the effectiveness of extended-length screens at Little Goose Dam, 1994. Report to U.S. Army Corps of Engineers, 13 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., B. P. Sandford, and D. B. Dey. 1996. Studies to evaluate the effectiveness of extended-length screens at Little Goose Dam, 1995. Report to U.S. Army Corps of Engineers, Contract E86920164, 12 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., B. P. Sandford, and D. B. Dey. 1997. Post-construction evaluation of the juvenile salmonid bypass system at Ice Harbor Dam, 1996. Report to U.S. Army Corps of Engineers, Contract E86960098, 14 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., J. G. Williams, D. A. Brege, R. F. Krcma, and D. R. Chambers. 1991. Juvenile salmonid guidance at Bonneville Dam Second Powerhouse, Columbia River, 1983-1989. N. Am. J. Fish. Manage. 11:400-412.

Gilbreath, L. G., E. M. Dawley, R. D. Ledgerwood, P. J. Bentley, and S. J. Grabowski. 1993. Relative survival of subyearling chinook salmon that have passed Bonneville Dam via the spillway or second powerhouse turbines or bypass system: adult recoveries through 1991. Report to the U.S. Army Corps of Engineers, Contract E96910013, 18 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gilbreath, L., and E. Prentice. 1999. Post construction evaluation of the modified Bonneville Dam Second Powerhouse juvenile bypass system. *In* Abstracts, Anadromous Fish Evaluations Program 1999 Annual Research Review, November 1999. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Giorgi, A. E. 1996. Spill effectiveness/efficiency: scoping the information. PATH Task 3.1.4a. Appendix 4 of Chapter 6. In D. Marmorek (editor). Plan for Analyzing and Testing Hypotheses (PATH): Final report on retrospective analyses for fiscal year 1996. ESSA Technologies Ltd., Vancouver, B.C., Canada.

Giorgi, A. E., M. Miller, and J. R. Stevenson. 2002. Mainstem passage strategies in the Columbia River system: transportation, spill, and flow augmentation. Report 2002-03, Northwest Power Planning Council, Portland, OR.

Giorgi, A. E., and J. R. Stevenson. 1995. A review of biological investigations describing smolt passage behavior at Portland District Corps of Engineer Projects: Implications to surface collection systems. Report to U.S. Army Corps of Engineers, 33 p. (Available from Don Chapman Consultants, Inc., Boise, ID 83705.)

Giorgi, A. E., L. C. Stuehrenburg, D. R. Miller, and C. W. Sims. 1985. Smolt passage behavior and flow-net relationship in the forebay of John Day Dam. Report to Bonneville Power Administration, Contract DE-A179-84BP39644, 85 p. plus Appendix.

Giorgi, A. E., G. A. Swan, W. S. Zaugg, T. Coley, and T. Y. Barila. 1988. Susceptibility of chinook salmon smolts to bypass systems at hydroelectric dams. N. Am. J. Fish Manage. 8:25-29.

Grant, B. F., and P. M. Mehrle. 1973. Endrin toxicosis in rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 30:31-40.

Hane, S., O. H. Robertson, B. C. Eexler, and M. A. Krupp. 1966. Adrenocortical responses to stress and ACTH in Pacific salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*) at successive stages in the sexual cycle. Endocrinology 78:791-800.

Hansel, H. C., N. S. Adams, T. D. Counihan, B. D. Liedtke, M. S. Novick, J. M. Plumb and T. P. Poe. 1999a. Estimates of fish and spill passage efficiency for radio-tagged juvenile steelhead and yearling chinook salmon at John Day Dam, 1999. Annual report of research to U.S. Army Corps of Engineers, Portland District, Portland, OR. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Hansel, H. and J. Beeman. 1999. Estimates of fish- and spill-passage efficiencies of radio-tagged juvenile chinook salmon and steelhead at John Day Dam. *In* Abstracts, Anadromous Fish Evaluations Program 1999 Annual Research Review, November 1999. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Hansel, H.C., J.W. Beeman, T.D. Counihan, J.M. Hardiman, B.D. Liedtke, N.S. Novick, and J.M. Plumb. 2000. Estimates of fish-, spill-, and sluiceway-passage efficiencies of radio-tagged juvenile steelhead and yearling chinook salmon at The Dalles Dam, 1999. U.S. Geological Survey report to U.S. Army Corps of Engineers, Portland District. 34 p. plus appendix.

Hansel, H. C., R.S. Shively, J. E. Hensleigh, B. D. Liedtke, R. E. Wardell, R.H. Wetheimer and T.P. Poe. 1999b. Movement, distribution, and behavior of radio-tagged juvenile chinook salmon and steelhead in the forebay of Bonneville Dam, 1998. Annual report of research to U.S. Army Corps of Engineers, Portland District, Portland, OR. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Hansel, H. C., R. S. Shively, G. S. Holmberg, T. P. King, T. L. Martinelli, and M. B. Sheer. 1993. Movements and distribution of radio-tagged northern squawfish near The Dalles and John Day dams. *In* T. Poe (editor), Significance of selective predation and development of prey protection measures for juvenile salmonids in the Columbia and Snake River reservoirs. Report to Bonneville Power Administration, Contract DE-AI79-88BP91964, 42 p. plus Appendix.

Harmon , J. R., K. L. Thomas, K. W. McIntyre, and N. N. Paasch. 1994. Prevalence of marine-mammal tooth and claw abrasions on adult anadromous salmonids returning to the Snake River. N. Am. J. Fish. Manage. 14:661-663.

Harmon, J. R., D. M. Marsh, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2000. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1999. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H0034. 28 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Haro, A., M. Odeh, J. Noreika, and T. Castro-Santos. 1998. Effect of water acceleration on downstream migratory behavior and passage of Atlantic salmon smolts and juvenile American shad at surface bypasses. Trans. Am. Fish. Soc. 127: 118-127.

Haskell, C. A., K. F. Tiffan, R. C. Koch, M. G. Mesa, and D. W. Rondorf. 2003. Water temperature effects on fall chinook salmon in the Snake and Columbia Rivers, 2002. Draft report of the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Hensleigh, J. E., R. S. Shively, H. C. Hansel, J. M. Hardiman, G. S. Holmberg, B. D. Liedtke, T.L. Martinelli. R. E. Wardell, R. H Wertheimer, and T. P. Poe. 1999. Movement, distribution, and behavior of radio-tagged juvenile chinook salmon and steelhead in John Day, The Dalles and Bonneville forebays, 1997. Report to U. S. Army Corps of Engineers, 34 p. plus Appendix. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Hensleigh, J. E., R. S. Shively, H. C. Hansel, B. D. Liedtke, K. M. Lisa, P. J. McDonald, and T. P. Poe. 1998. Movement, distribution, and behavior of radio-tagged juvenile chinook salmon and steelhead in the forebay of Bonneville Dam, 1998. Report to U.S. Army Corps of Engineers, 15 p. plus Appendix. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwoood Rd., Cook, WA 98605.)

Hockersmith, E.E., M. B. Eppard, G. A. Axel, B. P. Sandford. In prep. Lower Monumental Dam spillway-passage survival, 2003. Report to U.S. Army Corps of Engineers, Walla Walla District.

Hockersmith, E. E., S. G. Smith, W. D. Muir, B. P. Sandford, J. G. Williams, and J. R. Skalski. 1999. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997. Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, Project 93-29, 56 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Hockersmith, E. E., W. D. Muir, S. G. Smith, and B. P. Sandford. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling chinook salmon in the Snake and Columbia Rivers. North American Journal of Fisheries Management 23:404-413.

Holmberg, G. S., R. S. Shively, H. C. Hansel, T. L. Martinelli, M. B. Sheer, J. M. Hardiman, B. D. Liedtke, L. S.Blythe, and T. Poe. 1998. Movement, distribution, and behavior of radio-tagged juvenile chinook salmon in John Day, The Dalles, and Bonneville Dam forebays, 1996. Report to U.S. Army Corps of Engineers, 35 p. plus Appendixes. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Holmes, H. B. 1952. Loss of salmon fingerlings in passing Bonneville Dam as determined by marking experiments. Unpublished manuscript, U.S. Bureau of Commercial Fisheries Report to U.S. Army Corps of Engineers, North Pacific Division, Portland, OR, 52 p. (Available from U.S. Fish and Wildlife Service, Vancouver, WA.)

Hurson, D., and 17 coauthors 1996. Juvenile Fish Transportation Program. 1994 Annual Report. Walla Walla District, U.S. Army Corps of Engineers. 94 p. plus Appendices. (Available from U. S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Hurson, D., and 20 coauthors. 1999. Juvenile fish transportation program 1998 annual report. 112 p. plus Appendixes. (Available from U. S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Independent Economic Advisory Board (IEAB). 2004. Juvenile passage cost effectiveness analysis for the Columbia River Basin: Description and preliminary analysis. Northwest Power and Conservation Council, Document IEAB 2004-01. 32 p.

Independent Scientific Advisory Board (ISAB). 1999. Review of 1998 Draft Annual Report to the Oregon Department of Environmental Quality. Letter to William Stelle, January 5, 1999. 4 p. Available from Northwest Power Planning Council, 851 SW 6th Ave. Suite 1100, Portland, OR 97204.

Independent Scientific Group (ISG). 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Northwest Power Planning Council, Portland, Oregon. 522 p. plus Appendixes

Iwamoto, R. N., W. D. Muir, B. P. Sandford, K. W. McIntyre, D. A. Frost, J. G. Williams, S. G. Smith, and J. R. Skalski. 1994. Survival estimates for the passage of juvenile chinook salmon through Snake River dams and reservoirs, 1993. Report to Bonneville Power Administration, Portland, Oregon, Contract DE-AI79-93BP10891,126 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Iwamoto, R. N. and J. G. Williams. 1993. Juvenile salmonid passage and survival through turbines. Report to U.S. Army Corps of Engineers, Portland, OR, Contract E86920049, 27 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Jepson, M. A., C. L. Williams, C. A. Peery, and M. L. Moser. 2003. Effects of the shad fishery on passage of adult Chinook salmon through the Oregon-shore fishway ladder at The Dalles Dam - 2002. U.S. Army Corps of Engineers, Technical Report 2003-4, 11 p. (Available online at http://www.cnr.uidaho.edu/coop/download.htm).

Johnsen, R. C., and E. M. Dawley. 1974. The effect of spillway flow deflectors at Bonneville Dam on total gas supersaturation and survival of juvenile salmon. Report to U.S. Army Corps of Engineers, Contract DACW-57-74-F-0122, 19 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Johnson, G.E., and 6 coauthors. 2003. Hydroacoustic evaluation of turbine intake J-occlusions at The Dalles Dam in 2002. Final report prepared for U.S. Army Corps of Engineers. Contract DACW57-00-D-0009, Task Order No. 0009.

Johnson, G. E. 1996. Fisheries research on phenomena in the forebay of Wells Dam in spring 1995. Related to the Surface Flow Smolt Bypass. Report to U.S. Army Corps of Engineers, Walla Walla District, Contract 19478-Task 12, 62 p. plus Appendixes. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Johnson, L. 1984. Hydroacoustic evaluation of the efficiencies of the ice and trash sluiceway and spillway at Ice Harbor Dam for passing downstream migrating juvenile salmon and steelhead, 1983. BioSonics, Inc.

Johnson, G., N. Adams, R. Johnson, D. Rohdorf, D. Dauble, and T. Barila. 2000. Evaluation of the prototype surface bypass salmonid smolts in spring 1996 and 1997 at Lower Granite Dam on the Snake River, Washington. Trans. Am. Fish. Soc. 129: 381-397.

Johnson, G. E., S. M. Anglea, N. S. Adams, and T. O. Wik. In review. Evaluation of a prototype surface flow bypass for juvenile salmon at the powerhouse of Lower Granite Dam, Snake River, Washington, 1996-2000. N. Am. J. Fish. Mgt.

Johnson, R. L., S. M. Anglea, S. L. Blanton, M. A. Simmons, R. A. Moursund, G. E. Johnson, E. A. Kudera,, J. Thomas, and J. R. Skalski. 1999. Hydroacoustic evaluation of fish passage and behavior at Lower Granite Dam in spring 1998. Report to U.S. Army Corps of Engineers, Walla Walla, Washington, Contract DACW68-96-D-0002, 156 p. plus Appendixes (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla WA 99362.)

Johnson, G. E., and D. D. Dauble. 1995. Synthesis of existing physical and biological information relative to development of a prototype surface flow bypass system at Lower Granite Dam. Report to U.S. Army Corps of Engineers, Contract 19478-Task11, 41 p. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Johnson, G. E., A. Giorgi, C. Sweeney, M. Rashid, and J. Plump. 1999. High flow outfalls for juvenile fish bypasses: preliminary guidelines and plans for research and implementation. Report to U.S. Army Corps of Engineers, Contract DACW57-97-D0003, 58 p. plus Appendixes. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Johnson, G. E., M. Hanks, J. Hedgepeth, B. McFadden, R. Moursund, R. Mueler, and J. Skalski. 2003. Hydroacoustic evaluation of the J-occlusion plates at The Dalles Dam in 2002. Report to U.S. Army Corps of Engineers. Contract No.DACW57-00-D-0009, Task Order No. 0009. (Available from U.S. Army Corps of Engineers, Portland, OR.)

Johnson, G. E., R. Johnson, S. Anglea, S. Abernathy, S. Blanton, and M. Simmons. 1998. Fixed-location hydroacoustic evaluation of the prototype surface bypass and collector, spill efficiency, and fish guidance efficiency at Lower Granite Dam in spring and summer 1997. 25p. Final report prepared for U.S. Army Corps of Engineers. Contract No.DACW68-96-D-0002, Walla Walla, WA.

Johnson, R. L., G. E. Johnson, S. M. Anglea, S. L. Blanton, M. A. Simmons, S. Thorsten, E. A. Kudera, J. R. Skalski, and J. Thomas. 1998. Fixed location hydroacoustic evaluation of the prototype surface bypass structures at Lower Granite Dam in spring 1998. Report to U.S. Army Corps of Engineers, Walla Walla, Washington, Contract DACW68-96-D-0002, 103 p. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Johnson, R. L., G. E. Johnson, and D. E. Weitkamp. 1987. Hydroacoustic evaluation of the spill program for fish passage at The Dalles Dam in 1986. Report to U.S. Army Corps of Engineers, Portland, Oregon, Contract DACW57-81-F-0343, 36 p. plus Appendixes.

Johnston, S. and P. Nealson. 1999. Hydroacoustic smolt passage and spill effectiveness studies at John Day Dam in 1999. *In* Abstracts, Anadromous Fish Evaluations Program 1999 Annual Research Review, November 1999. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.)

Johnson, R. L., C. Noyes and R. McClure. 1983. Hydroacoustic evaluation of the ice and trash sluiceway and spillway at Ice Harbor Dam for passing downstream migrating juvenile salmon and steelhead, 1983. Vol. 1. Report to U.S. Army Corps of Engineers, Contract DACW68-82-C-0066, 29 p. plus Appendixes.

Johnson, G. E., C. M. Sullivan, and M. W. Erho. 1992. Hydroacoustic studies for developing a smolt bypass system at Wells Dam. Fish. Res. 14:221-37.

Johnson, R.L., and 6 coauthors. 2001. Hydroacoustic evaluation of fish behavior at Bonneville Dam First Powerhouse: 2000 prototype surface flow bypass. Report to U.S. Army Corps of Engineers. Contract No.DACW 68-96-D-002, 58 p. plus Appendices. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Jones, T. J., G. M. Starke, and R. J. Stansell. 1997. Predation by gulls and effectiveness of predation control measures at Bonneville, The Dalles and John Day Dams, in 1996. 19 p. (Available from U.S. Army Corps of Engineers, CENWP-CO-SRF, Bonneville Lock and Dam, Cascade Locks, OR 97014.)

Junge, C. 1967. Standardization of spill patterns at Ice Harbor Dam. Oregon Fish Commission, Report to U.S. Army Corps of Engineers, Contract DACW68-67-C0108, 24 p.

Karr, M.H. J. K. Fryer, and P. R. Mundy. 1998. Snake River Water Temperature Control Project, Phase II. Report to Environmental Protection Agency, Region 10, Contract X0990375-01-1, and National Marine Fisheries Service, Contract WASC-6-2160. 209 p.

Katz, D. M. 1996. Juvenile fish separator design. *In* Chenchayya Bathala, (editor), Conference Proceedings, North American Water and Environment Congress & Destructive Water, New York, NY. p. 1117-1122

Katz, D. M., R. L. McComas and L. J. Swenson. 1999. Juvenile fish separation in a high-velocity flume. Paper for the American Society of Civil Engineers, Seattle, WA., 9-12 August, 1999.

Keefer, M. L., and T. C. Bjornn. 1999. Evaluation of adult salmon and steelhead migrations past dams and through reservoirs in the Columbia River Basin. Handout presented at the COE Anadromous Fish Evaluation Program Annual Review, November 14-18, 1999, Walla Walla, WA, 10 p. (Available from U.S. Army Corps of Engineers, Walla Walla, WA.)

Keefer, M. L., T. C. Bjornn, C. A. Peery, K. R. Tolotti, R .R. Ringe, and P. J. Keniry. 2002. Migration of adult steelhead past Columbia and Snake River dams, through reservoirs, and distribution into tributaries, 1996. U.S. Army Corps of Engineers, Technical Report 2002-2, 183 p. (Available online at http://www.nwp.usace.army.mil/pm/e/afep_reports.htm).

Keefer, M. L., T. C. Bjornn, C. A. Peery, K. R. Tolotti, R. R. Ringe, and L. C. Stuehrenberg. 2003a. Adult spring and summer Chinook salmon passage through fishways and transition pools at Bonneville, McNary, Ice Harbor, and Lower Granite Dams - 1996. U.S. Army Corps of Engineers, Technical Report 2003-5, 136 p. (Available online at http://www.cnr.uidaho.edu/coop/download.htm).

Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. In press. Upstream migration rates of radio-tagged adult Chinook salmon in the Columbia River Basin. J. Fish Biol.

Keefer, M. L., C. A. Peery, and B. J. Burke. 2003b. Passage of radio-tagged adult salmon and steelhead at John Day Dam with the emphasis on fishway temperatures: 1997-1998. U.S. Army Corps of Engineers, Technical Report 2003-1, 20 p. (Available online at http://www.cnr.uidaho.edu/coop/download.htm).

Keefer, M. L., C. A. Peery, M. A. Jepson, K. R. Tolotti, and L.C. Stuehrenberg. In review (b). Stock-specific migration timing of adult spring-summer Chinook salmon in the Columbia River basin. N. Amer. J. Fish. Manage.

Keniry, P. J., and T. C. Bjornn. 1998. Evaluation of temperature in adult fishways and forebays at Ice Harbor and Lower Granite Dams. Abstract presented at 1998 AFEP Annual Research Review, 13-15 October, 1998. 1 p.

Krasnow, L. D. 1998. Fish guidance efficiency (FGE) estimates for juvenile salmonids at lower Snake and Columbia River dams, Draft Report, April 3, 1998. (Available from National Marine Fisheries Service, Hydropower Program, 525 NE Oregon St., Portland, OR. 97232-2737)

Krcma, R. F., D. A. Brege, and R. D. Ledgerwood. 1986. Evaluation of the rehabilitated juvenile salmonid collection and passage system at John Day Dam - 1985. Report to U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 25 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA. 98112-2097.)

Krcma, R.F., D. DeHart, M. H. Gessel, C. Long, and C. W. Sims. 1982. Evaluation of submersible traveling screens, passage of juvenile salmonids through the ice-trash sluiceway, and cycling of gatewell orifice operations at the Bonneville first powerhouse, 1981. NMFS Coastal Zone and Estuarine Studies Division. Final report to the U.S. Army Corps of Engineers, Contract DACW57-81-F-0343, 36 p. plus Appendix.

Krcma, R.F., M. H. Gessel, W. D. Muir, C. S. McCutcheon, L. G. Gilbreath, and B. H. Monk. 1984. Evaluation of the juvenile collection and bypass system at Bonneville Dam - 1983. Report to U.S. Army Corps of Engineers, Contract DACW57-83-F-0315, 56 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Kumagai, K. K, B. H. Ransom, and H. A. Sloan. 1996. Effectiveness of a prototype surfaceflow attraction channel for passing juvenile salmon and steelhead trout at Wanapum Dam during the spring and summer 1996. Report to Grant County Public Utility District, Ephrata, WA.

Kumagai, K., B. Ransom, and H. Sloan. 1997. Effectiveness of a prototype surfaceflow attraction channel for passing juvenile salmon and steelhead trout at Wanapum Dam during the spring and summer 1997. (In-house draft report) Report to Grant County Public Utility District, Ephrata, WA.

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, P. J. Bentley, B. P. Sandford, and M. H. Schiewe. 1990. Relative survival of subyearling chinook salmon that have passed Bonneville Dam via the spillway or the second powerhouse turbines or bypass system in 1989, with comparisons to 1987 and 1988. Report to U.S. Army Corps of Engineers, Contract E85890024/E86890097, 64 p. plus Appendixes. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, P. J. Bentley, B. P. Sanford, and M. H. Schiewe. 1991. Relative survival of subyearling chinook salmon that have passed through the turbines or bypass system of Bonneville Dam Second Powerhouse, 1990. Report to the U.S. Army Corps of Engineers, Contract E86900104, 48 p. plus Appendixes. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Ledgerwood, R. D., E. M. Dawley, L. G. Gilbreath, L. T. Parker, B. P. Sanford, and S. J. Grabowski. 1994. Relative survival of subyearling chinook salmon at Bonneville Dam, 1992. Report to U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 53 p. plus Appendixes. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Ledgerwood, R. D., G. A. Swan, and R. F. Krcma. 1987. Fish guiding efficiency of submersible traveling screens at Lower Monumental Dam - 1986. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 33 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Liedtke, T. L., H. C. Hansel, J. M. Hardiman, G. S. Holmberg, B. D. Liedtke, R.S. Shively, and T.P. Poe. 1999. Movement, distribution and behavior of radio-tagged juvenile salmon at John Day Dam, 1998. Report U.S. Army Corps of Engineers, 41 p. plus Appendix. (Available from U.S. Geological Survey, Biological Resources Division, 5501A Cook-Underwood Rd., Cook, WA 98605.)

Liscom, K. L., G. E. Monan, and L. Stuehrenberg. 1979. Radio tracking studies relating to fallback at hydroelectric dams on the Columbia and Snake rivers. *In* Fifth Progress Report on Fisheries Engineering Research Program 1973-78. U.S. Army Corps of Engineers, North Pacific Division, Portland, OR., p. 39-53.

Liscom, K. L., G. E. Monan, L. Stuehrenberg, and P. J. Wilder. 1985. Radio-tracking studies on adult chinook salmon and steelhead trout at lower Columbia River hydroelectric dams, 1971-77. NOAA Technical Memorandum NMFS F/NWC-81, 225 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Liscom, K. L., L. Stuehrenberg, and F. Ossiander. 1985. Radio-tracking studies of adult chinook salmon and steelhead to determine the effect of “zero” river flow during water storage at Little Goose Dam on the lower Snake River. Report to Bonneville Power Administration, Contract DE-AI79-81BP27780, 64 p.

Long, C. W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. Fish. Bull. U.S. 66(3):599-609.

Long, C. W., R. F. Krcma, and F. J. Ossiander. 1968. Research on fingerling mortality in Kaplan turbines -1968. U.S. Bureau of Commercial Fisheries, Seattle, WA, 7 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Long, C. W., W. M. Marquette, and F. J. Ossiander. 1972. Survival of fingerlings passing through a perforated bulkhead and modified spillway at Lower Monumental Dam, April-May 1972. Report to U.S. Army Corps of Engineers, Contract DACW68-72-C-0101, 7 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Long, J. B., and L. E. Griffin. 1937. Spawning and migratory habits of the Columbia River steelhead trout as determined by scale studies. Copeia 1937:62.

Magne, R. A., W. T. Nagy, and W. C. Maslen. 1983. Hydroacoustic monitoring of downstream migrant juvenile salmonid passage at John Day and The Dalles Dams in 1982. U.S. Army Corps of Engineers, Portland, Oregon, 61 p.

Marmorek, D. R., and C. N. Peters (editors). 1998. Plan for Analyzing and Testing Hypotheses (PATH): Preliminary decision analysis report on Snake River spring/summer chinook. Report compiled by ESSA Technologies Ltd. Vancouver, BC. 92 p. plus Appendixes.

Marsh, D. M., B. P. Sandford, and G. M. Matthews. 1995. Preliminary evaluation of the new juvenile collection, bypass, and sampling facilities at Lower Monumental Dam, 1993. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 47 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Marsh, D. M., B. H. Monk, B. P. Sandford and G. M. Matthews. 1996. Preliminary evaluation of the new juvenile collection, bypass, and sampling facilities at McNary Dam, 1994. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 39 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Marsh, D. M., J. R. Harmon, K. W. McIntyre, K. L. Thomas, N. N. Paasch, B. P. Sandford, D. J. Kamikawa, and G. M. Matthews. 1996. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1995. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H0034. 43 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Marsh, D. M., J. R. Harmon, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 1997. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1996. Report to U.S. Army Corps of Engineers, Delivery Order E86960099. 26 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Marsh, D. M., J. R. Harmon, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2000. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1998. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H0034. 34 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Marsh, D. M., J. R. Harmon, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2001. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2000. Report to U.S. Army Corps of Engineers, Delivery Order E86960099. 27 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Marsh, D. M., J. R. Harmon, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2003. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2001. Report to U.S. Army Corps of Engineers, Delivery Order E86960099. 33 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Marsh, D. M., J. R. Harmon, N. N. Paasch,, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2004. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2002. Report to U.S. Army Corps of Engineers, Delivery Order E86960099. 35 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Martinelli, T. L., H. C. Hansel, and R. S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia 371/372:79-87.

Martinson, R. D., R. J. Graves, M. J. Langslay, and S. D. Killins. 1996. Monitoring of downstream salmon and steelhead at federal hydroelectric facilities-1995. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-85BP20733, 16 p. plus Appendixes.

Martinson, R. D., R. J. Graves, R. B. Mills, and J. W. Kamps. 1997. Monitoring of downstream salmon and steelhead at federal hydroelectric facilities - 1996. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-85BP20733, 18 p. plus Appendixes

Martinson, R. D., J. W. Kamps, G. M. Kovalchuk, and D. Ballinger. 1999. Monitoring of downstream salmon and steelhead at federal hydroelectric facilities-1998. Report to Bonneville Power Administration, Portland, OR. Contract DE-AI79-85BP20733, 24 p. plus Appendixes.

Martinson, R., J. Kamps, G. Kovalchuk, D. Ballinger. 2002. Monitoring of downstream salmon and steelhead at federal hydroelectric facilities. Report to Bonneville Power Administration, Contract DOE/BP-00003992-2, Project No. 1987-12700. 80 electronic p.

Martinson, R. D., G. M. Kovalchuk, R. B. Mills, and J. W. Kamps. 1998. Monitoring of downstream salmon and steelhead at federal hydroelectric facilities - 1997. Report to the Bonneville Power Administration, Portland, OR. Contract DE-AI79-85BP20733, 64 p. plus Appendices.

Mathur, D., P. G. Heisey, E. T. Euston, J. R. Skalski, and S. Hays. 1996. Turbine passage survival estimation for chinook salmon smolts (*Oncorhynchus tshawytscha*) at a large dam on the Columbia River. Can. J. Fish. Aquat. Sci. 53:542-549.

Mathur, D., P. G. Heisey, J. R. Skalski, and D. R. Kenney. 2000. Salmonid smolt survival relative to turbine efficiency and entrainment depth in hydroelectric power generation. Journal of the American Water Resources Association 36: 737-747.

Matter, A. L. and B. P. Sandford. 2003. A comparison of migration rates of radio- and PIT-tagged adult Snake River Chinook salmon through the Columbia River hydropower system. N. Amer. J. Fish. Manage. 23(3): 967-973.

Maule, A. G., C. B. Schreck, C. S. Bradford, and B. A. Barton. 1988. Physiological effects of collecting and transporting emigrating juvenile chinook salmon past dams on the Columbia River. Trans. Am. Fish. Soc. 117: 245-261.

Maule A. G., J. W. Beeman, K. M. Hans, M. G. Mesa, P. Haner, and J. J. Warren. 1997. Gas bubble trauma monitoring and research of juvenile salmonids. Annual Report to Bonneville Power Administration, OR, Contract 96-AI-93279, 117 .

Mazeaud, M. M., F. Mazeaud, and E. M. Donaldson. 1977. Primary and secondary effects of stress in fish: some new data with a general overview. Trans. Am. Fish. Soc. 106:201-212.

McComas, R. L., D. A. Brege, W. D. Muir, B. P. Sandford, and D. B. Dey. 1993. Studies to determine the effectiveness of extended-length submersible bar screens at McNary Dam, 1992. Report to U.S. Army Corps of Engineers, Contract E86910060, 34 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 1998. Studies to establish biological design criteria for wet-separators, 1996. Report to U.S. Army Corps of Engineers, Contract E86910060, 31 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, and D. B. Dey. 1994. Studies to determine the effectiveness of extended-length submersible bar screens at McNary Dam, 1993. Report to U.S. Army Corps of Engineers, Contract E86910060, 25 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, and D. B. Dey. 1995. Vertical barrier screen studies at McNary Dam, 1994. Report to U.S. Army Corps of Engineers, Contract E86910060, 32 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L.,B. P. Sandford, and D. B. Dey. 1997. Descaling and orifice passage efficiency studies at McNary Dam, 1995. Report to U.S. Army Corps of Engineers, Delivery Order E86910060, 35 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 1998. Studies to establish biological design criteria for wet separators, 1996. 24 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2000. Studies to establish biological design criteria for fish passage facilities: Improved wet-separator efficiency and high velocity flume development, 1997. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2001. Biological design criteria for fish passage, 1998: High velocity flume development and improved wet-separator efficiency (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, C. D. Magie, J. W. Ferguson, D. M. Katz, and M. Plummer. 2003. Evaluation of a prototype separator at Ice Harbor Dam, 1999. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, C. D. Magie and J. W. Ferguson. 2003. Biological design criteria for fish passage facilities: High velocity flume development and improved wet-separator efficiency , 1999. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, C. D. Magie, J. W. Ferguson and D. M. Katz. In prep a. Biological design criteria for fish passage facilities: High velocity flume development and improved wet-separator efficiency , 2000. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McComas, R. L., B. P. Sandford, C. D. Magie, J. W. Ferguson and D. M. Katz. In prep b. Biological design criteria for fish passage facilities: High velocity flume development and improved wet-separator efficiency , 2001. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Summary of technical literature examining the physiological effects of temperature on salmonids. Issue paper 5. Environmental Protection Agency, EPA-910-D-01-005

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U. S. Dept. of Commer., NOAA Tech. Memo. NMFS-NWFSC-42, 156 p.

McFaden, B. D. 1988. Hydroacoustic evaluation of juvenile fish passage at Lower Monumental Dam in 1988. Report to U.S. Army Corps of Engineers, Contract DACW68-88-C-0021, 27 p. plus Appendixes. (Available from Biosonics Inc., 4027 Leary Way N.W., Seattle, WA 98107.)

McMaster, K. M., R. G. White, R. R. Ringe, and T.C. Bjornn. 1977. Effects of reduced nightime flows on upstream migration of adult chinook salmon and steelhead trout in the lower Snake River. Report to U.S. Army Corps of Engineers, Contract DACW8-76-C-0016, 64 p.

Meekin, T. K., and R. L. Allen. 1974. Summer chinook and sockeye salmon mortality in the Upper Columbia river and its relationship to nitrogen supersaturation. Washington Department of Fisheries, Technical Report 12:127-153.

Mendel, G., and D. Milks. 1996. Upstream passage and spawning of fall chinook salmon in the Snake River. Available from Washington Department of Fish and Widllife, Hatcheries Program, Olympia, WA 98504. 51 p. plus Appendixes.

Merrell, T. R., Jr., M. D. Collins, and J. W. Greenough. 1971. An estimate of mortality of chinook salmon in the Columbia River near Bonneville Dam during the summer run of 1955. U.S. Fish Wild. Serv., Fish. Bull., U.S. 68:3:461-492.

Mesa, M. G., L. K. Weiland, and A. G. Maule. 2000. Progression and severity of gas bubble trauma in juvenile salmonids. Trans. Am. Fish. Soc. 129: 174-185.

Mesa, M. G., L. K. Weiland, and P. Wagner. 2002. Effects of acute thermal stress on the survival, predator avoidance, and physiology of juvenile fall chinook salmon. Northwest Sci. 76(2):118-128.

Mesa, M. G., A. G. Maule, and C. B. Schreck. 2000. Interaction of infection with *Renibacterium salmoninarum* and physical stress in juvenile chinook salmon: physiological responses, disease progression, and mortality. Trans. Am. Fish. Soc. 129:158-173.

Mesa, M. G., and C. B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Trans. Am. Fish. Soc. 118:644-658.

Mighetto, L., and W. J. Ebel. 1994. Saving the salmon: a history of the U.S. Army Corps of Engineers' efforts to protect anadromous fish on the Columbia and Snake Rivers. Historical Research Associates, Inc., 119 Pine St., Suite 207, Seattle, WA 98101. 262 p. plus Appendixes.

Monan, G. E., and K. L. Liscom. 1975. Radio-tracking studies to determine the effect of spillway deflectors and fallback on adult chinook salmon and steelhead trout at Bonneville Dam, 1974. Report to U.S. Army Corps of Engineers, Portland, OR, Contract DACW57-74-F-0122, 38 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., R. F. Absolon, and E. M. Dawley. 1997a. Changes in gas bubble disease signs and survival of migrating juvenile salmonids experimentally exposed to supersaturated gasses. Report to Bonneville Power Administration, Portland OR, Contract 96-BI-93892, 27 p.

Monk, B. H., M. H. Gessel, and J. W. Ferguson. 1999a. An evaluation of the biological database for improving fish guiding efficiency at Bonneville Dam Second Powerhouse. Report to U.S. Army Corps of Engineers, Contract W66QKZ90059456, 62 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., J. A. Ross, B.P. Sandford, and D. B. Dey. 1993. Continuing studies to measure and improve fish guidance efficiency of submersible traveling screens at Bonneville Dam First Powerhouse Report to U.S. Army Corps of Engineers, Contract E96910012. 24 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097.)

Monk, B. H., B. P. Sandford, and D. B.Dey. 1994. Evaluation of fish guidance efficiency of submersible traveling screens and other modifications at Bonneville Dam Second Powerhouse, 1993. Report to U.S. Army Corps of Engineers, Contract E96930031. 26 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097.)

Monk, B. H., B. P. Sandford, and D. B.Dey. 1995. Evaluation of fish guidance efficiency of submersible traveling screens and other modifications at Bonneville Dam Second Powerhouse, 1994. Report to U.S. Army Corps of Engineers, Contract E96940027. 15 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097.)

Monk, B. H., B. P. Sandford, and D. B. Dey. 1998. Evaluation of extended-length bar screens at Bonneville Dam First Powerhouse, 1998. Report to U.S. Army Corps of Engineers, Portland District, Portland OR, 27 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., B. P. Sandford, and D. B. Dey. 1997b. Evaluation of orifice passage efficiency and descaling with an extended-length bar screen, new vertical barrier screen, and inlet flow vane at Lower Granite Dam, 1995. Report to U.S. Army Corps of Engineers, Contract E86950104, 19 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., B. P. Sandford, and D. B. Dey. 1999b. Evaluation of extended-length bar screens at Bonneville Dam First Powerhouse, 1998. Report to U.S. Army Corps of Engineers, Contract W66QKZ80545753, 32 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., G. E. Varney, S. J. Grabowski. 1992a. Continuing studies to evaluate and improve submersible traveling screens for fish guidance at Bonneville Dam First Powerhouse. Report to U.S. Army Corps of Engineers, Contract E96910012. 20 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097).

Monk, B. H., B. P. Sandford, and J. W. Williams. 1992b. Evaluation of the fish collection, transportation, and bypass facility at Little Goose Dam, 1990. Report to U.S. Army Corps of Engineers, Contract E86900057, 32 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. M., R. F. Absolon, B. P. Sandford, and J. W. Ferguson. 2002. Evaluation of intake modifications at Bonneville Dam Second Powerhouse, 2001. Report to the U.S. Army Corps of Engineers, Contract W66QKZ80545753. 24 p. plus appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Moser, M. L., and D. A. Close. 2003. Assessing Pacific lamprey status in the Columbia River Basin. Northwest Science 77(2):116-125.

Mosey, T. R. 2003. Biological evaluation of the Rocky Reach juvenile fish bypass system, 2003. Prepared for the Chelan County PUD. Draft

Mosey, T. R., K.G. Murdoch, and B.M. Bickford.. 1999. Biological and hydraulic evaluation of the Rocky Reach surface collector-1998. 60 p. plus Appendixes. (Available from Chelan Public Utility District, Wenatchee, WA.)

Moursund, R. A., K. D. Ham, and P. S. Titzler. 2003. Hydroacoustic evaluation of downstream fish passage at John Day Dam in 2002. Report to U.S. Army Corps of Engineers, Portland Dsictrict.

Moursund, R. A., K. D. Ham, P. S. Titzler, and F. Khan. 2003. Hydroacoustic evaluation of the effects of spill treatments on fish passage at Ice Harbor Dam in 2003. Abstract, U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Annual Review 2003, Walla Walla, WA.

Moursund, R. E., K. D. Ham, B. D. McFadden, G. E. Johnson. 2001a. Hydroacoustic evaluation of downstream fish passage at The Dalles Dam in 2001. Draft Final Report to the U.S. Army Corps of Engineers, Portland District. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla WA.)

Moursand, R., K. Ham, B. McFadden, G. Johnson. 2001b. Hydroacoustic evaluation of downstream fish passage at John Day Dam in 2000. Report to U.S. Army Corps of Engineers. Contract No.DACW 69-96-D-002, 58 p. plus Appendices. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Moursand, R., K. Ham, B. McFadden, and G. Johnson. 2001c. Hydroacoustic evaluation of downstream fish passage The Dalles Dam in 2000. Draft Final Report to U.S. Army Corps of Engineers. Contract No.DACW 57-00-D-0009. Task Order No. 0009.

Muir, W. D., R. N. Iwamoto, C. R. Pasley, B. P. Sandford, P. A. Ocker, and T. E. Ruehle. 1995b. Relative survival of juvenile chinook salmon after passage through spillways and the tailrace at Lower Monumental Dam, 1994. Report to U.S. Army Corps of Engineers, Contract E86940101, 28 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, E. E. Hockersmith, S. Achord, R. F. Absolon, P. A. Ocker, B. M. Eppard, T. E. Ruehle, J. G. Williams, R. N. Iwamoto, and J. R. Skalski. 1996. Survival estimates for the passage of yearling chinook salmon and steelhead through Snake River dams and reservoirs, 1995. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, and U.S. Army Corps of Engineers, Walla Walla, WA, Project E86940119, 150 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, R. N. Iwamoto, D. J. Kamikawa, K. W. McIntyre, E. E. Hockersmith, B.P. Sandford, P. A. Ocker, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1995a. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, and U.S. Army Corps of Engineers, Walla Walla, WA, Project E86940119, 187 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, K. W. McIntyre, and B. P. Sandford. 1998. Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997. Report to U.S. Army Corps of Engineers, Contract E86970085, 47 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001a. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River Dams. N. Am. J. Fish. Manage. 21:135-146.

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalaski. 2001b. Survival estimates for migrant yearling chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia Rivers, 1993-1998. N. Am. J. Fish Manage. 21:269-282.

Muir, W., S. Smith, R. Zabel, D. Marsh, J. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs. Project No. 1993-02900, 96 electronic pages. (BPA Report DOE/BP-00004922-3)

National Marine Fisheries Service (NMFS). 1995. Biological Opinion - Reinitiation of Consultation on 1994-1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years. 166 p.

National Marine Fisheries Service (NMFS). 1996. Gas bubble disease research priorities, 1996. 13 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

National Marine Fisheries Service (NMFS). 1997. 1996 Annual report to the Oregon Department of Environmental Quality. 64 p. plus Appendixes. (Available from Environmental and Technical Services Division, 525 N.E. Oregon St., Suite 500, Portland OR 97232-2737.)

National Marine Fisheries Service (NMFS). 1998a. 1997 annual report to the Oregon Department of Environmental Quality. 54 p. plus Appendixes. (Available from Environmental and Technical Services Division, 525 N.E. Oregon St., Suite 500, Portland OR 97232-2737.)

National Marine Fisheries Service (NMFS). 1998b. Supplemental Biological Opinion on 1994-1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years. 126 p. plus Appendixes. (Available from Environmental and Technical Services Division, 525 N.E. Oregon St., Suite 500, Portland OR 97232-2737.)

National Marine Fisheries Service (NMFS). 1999a. An assessment of lower Snake River hydrosystem alternatives on survival and recovery of Snake River salmonids. 137 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

National Marine Fisheries Service (NMFS). 1999b. 1998 annual report to the Oregon Department of Environmental Quality. 64 p. plus Appendixes. (Available from Environmental and Technical Services Division, 525 N.E. Oregon St., Suite 500 Portland OR 97232-2737.)

National Marine Fisheries Service (NMFS). 1999c. Report to Congress: impacts of California sea lions and Pacific harbor seals on salmonids and west coast ecosystems. 18 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

National Marine Fisheries Service (NMFS). 2000. Biological Opinion - Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin. 180 p.

National Marine Fisheries Service (NMFS). 2003. Water temperature modeling and data collection plan for lower Snake River basin. Bi-Op measure 143 final report by the RPA 143 Workgroup. National Marine Fisheries Service. Available http://www.nwr.noaa.gov/1hydrop/hydroweb/docs/RPAFinalReport.pdf (December 2003).

National Marine Fisheries Service (NMFS). 2004. Anadromous salmonid passage facility guidelines and criteria. (Available from Environmental and Technical Services Division, 525 N.E. Oregon St., Suite 500, Portland OR 97232-2737.)

National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. 417 p. plus Appendixes. National Academy Press, Washington, D.C.

Naughton, G., and C.A. Peery. 2003. Lower Granite transition pool weir test - 2001 and 2002. U.S. Army Corps of Engineers, Letter Report, 4 p. (Available online at http://www.cnr.uidaho.edu/coop/download.htm).

Nestler, J. M. and R. A. Davidson. 1995. Imaging smolt behavior on bypass screens and a vertical barrier screen at McNary Dam in 1992. COE Report WES EL-95-21. Report to U.S. Army Corps of Engineers, Portland, OR. (Available from U.S. Army Corps of Engineers, Portland, OR.)

Nestler, J. M. and A. Goodwin. In prep. Movement behavior of outmigrating juvenile salmon near hydraulic structures. (Available from the U.S. Army Engineer Research and Development Center, Vicksburg, MS)

Nichols, D. W. 1979. Passage efficiency and mortality studies of downstream migrant salmonids using The Dalles Dam ice-trash sluiceway during 1978. Oregon Department of Fish and Wildlife. Report to U.S. Army Corps of Engineers, Portland, OR, 28 p.

Nichols, D. W., and B. H. Ransom. 1980. Development of The Dalles Dam trash sluiceway as a downstream migrant bypass system, 1980. Oregon Department of Fish and Wildlife. Report to U.S. Army Corps of Engineers, Portland, OR, Contract DACW57-78-C0058, 36 p. plus Appendix.

Nichols D. W., and B. H. Ransom. 1981. Development of The Dalles Dam trash sluicway as a downstream migrant bypass system, 1981. Oregon Department of Fish and Wildlife. Report to U.S. Army Corps of Engineers, Portland, OR. Contract DACW57-78-C0058, 34 p. plus Appendix.

Normandeau Associates, Inc. 2003a. Feasibility of estimating passage survival of adult salmonids using the Hi-Z tag-recapture technique. Report prepared for U.S. Army Corps of Engineers, Contract No. DACW68-02-D-0002, Walla Walla District.

Normandeau Associates, Inc. 2003b. Estimated direct mortality and injury of juvenile salmonids in passage through The Dalles Dam spillway, Columbia River in spring and summer 2002. Report to U.S. Army Corps of Engineers, Portland District. 17 p. plus appendices.

Normandeau Associates Inc., Mid-Columbia Consulting Inc., and J. R. Skalski. 2004. Direct effects of differential spill volumes on mortality and injury rates of juvenile salmonids at The Dalles Dam spillway, Columbia River in fall 2002, and spring 2003. Report to U.S. Army Corps of Engineers, Portland District. 19 p. plus tables, figures, and appendices.

Normandeau Associates, Inc., and J. R. Skalski. 1996a. Relative survival of juvenile chinook salmon (Oncorhynchus tshawytscha) in passage through a modified Kaplan turbine at Rocky Reach Dam, Columbia River, Washington. Normandeau Associates, Inc. Report for Public Utility District 1 of Chelan County, Wenatchee, Washington.

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1995. Turbine passage survival of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at Lower Granite Dam, Snake River, Washington. Report to U.S. Army Corps of Engineers. Contract DACW68-95-C-0031, 78 p. (Available from U.S. Army Corps of Engineers, Walla Walla, WA.)

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1996a. Draft report on potential effects of spillway flow deflectors on fish condition and survival at the Bonneville Dam, Columbia River. Report to the U.S. Army Corps of Engineers, Contract DACW57-95-C-0086, 51 p. plus Appendixes (Available from U.S. Army Corps of Engineers, Portland, OR 97208.)

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1996b. Potential effects of modified spillbay configurations on fish condition and survival at The Dalles Dam, Columbia River. Report to U.S. Army Corps of Engineers, Contract DACW57-95-C-0086, 59 p. plus Appendixes (Available from U.S. Army Corps of Engineers, Portland, OR 97208.)

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1996c. Fish survival investigation relative to turbine rehabilitation at Wanapum Dam, Columbia River, Washington. Report to Grant County Public Utilities District, Ephrata, WA. (Available from Normandeau Associates, Drumore, PA 17518.)

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1997. Juvenile steelhead passage survival through a flow deflector spillbay versus a non-flow deflector spillbay at Little Goose Dam, Snake River, Washington. Report to U. S. Army Corps of Engineers, Contract DACW68-96-D-0003. (Available from U. S. Army Corps of Engineers, Walla Walla, WA 99362.)

Normandeau Associates Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 1999. Relative passage survival and injury mechanisms for chinook salmon smolts within the turbine environment at McNary Dam, Columbia River. Draft Report to U. S. Army Corps of Engineers, Contract DACW68-96-D-0003. (Available from U. S. Army Corps of Engineers, Walla Walla, WA 99362.)

Normandeau Associates, Inc., J. R. Skalski, and Mid-Columbia Consulting Inc. 2000. Direct passage survival and condition of juvenile chinook salmon passed through an existing and new minimum gap runner turbines at Bonneville Dam, First Powerhouse, Columbia River. Normandeau Associates, Inc. report for U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Normandeau Associates, J. R. Skalski, and Mid Columbia Consulting Inc. 2002. Passage survival and fish condition at the removable spillway weir at Lower Granite Dam, Snake River. Report to the U.S. Army Corps of Engineers, Contract No. DACW68-96-D-003, Task Order 0021. (Available from Normandeau Associates, Inc., 1921 River Road, Drumore, PA 17518).

Normandeau Associates, J. R. Skalski, and Mid Columbia Consulting Inc. 2003c. Survival/condition of chinook salmon smolts under different turbine operations at McNary Dam, Columbia River. Report to U.S. Army Corps of Engineers, Walla Walla District, 37 p. plus appendices.

North, J.A., R. C. Beamesderfer, and T. A. Rien. 1993. Distribution and movements of white sturgeon in three lower Columbia River reservoirs. Northwest Science 67:105-111.

North, J. A., T. A. Rien, and R. A. Farr. In press. Report A in K.T. Beiningen, editor. Effects of mitigative measures on productivity of white sturgeon populations in the Columbia River downstream from McNary Dam, and status and habitat requirements of white sturgeon populations in the Columbia and Snake rivers upstream from McNary Dam. Annual report to the Bonneville Power Administration.

Northwest Power Planning Council (NPPC). 1982. Columbia River Basin Fish and Wildlife Program. (Available from Northwest Power Planning Council, 851 SW 6th Avenue, Suite 1100, Portland, OR 97204-1348.)

Northwest Power Planning Council (NPPC). 1984. 1984 Columbia River Basin Fish and Wildlife Program. (Available from Northwest Power Planning Council, 851 SW 6th Avenue, Suite 1100, Portland, OR 97204-1348.)

Northwest Power Planning Council (NPPC). 1986. Compilation of information on salmon and steelhead losses in the Columbia River Basin. Appendix D, Columbia River Basin Fish and Wildlife Program. (Available from Northwest Power Planning Council, 851 SW 6th Avenue, Suite 1100, Portland, OR 97204-1348.)

ODFW and WDFW. 1998. Status report: Columbia River fish runs and fisheries, 1938-1997. 299 p. (Available from Oregon Department of Fish and Wildlife, Portland OR 97208.)

Oligher, R. C., and I. J. Donaldson. 1966. Fish passage through turbines, test at Big Cliff hydroelectric plant. Report to U.S. Army Corps of Engineers, Walla Walla District. Progress Report 6, 15 p.

Oregon Fish Commission. 1960. Results of a tagging program to enumerate the numbers and to determine the seasonal occurrence of anadromous fish in the Snake River and its tributaries. Report to U.S. Army Corps of Engineers, North Pacific Division, Portland OR. *In* U.S. Army Corps of Engineers, Progress Report on the Fisheries Engineering Research Program, Portland, OR. Pages 20-22. (Available from U. S. Army Engineer District, Portland, OR.)

Pacific Northwest National Laboratory, BioAnalysts, ENSR International Inc., and Normandeau Associates Inc. 2001. Design guidelines for high-flow smolt bypass outfalls: field, laboratory, and modeling studies. Prepared for the U.S. Army Corps of Engineers. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Park, D. L., G. M. Matthews, T. E. Ruehle, J. R. Smith, J. R. Harmon, B. H. Monk, and S. Achord. 1983. Evaluation of transportation and related research on the Columbia and Snake Rivers, 1982. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H0034. 47 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Park, D. L., G. M. Matthews, J. R. Smith, T. E. Ruehle, J. R. Harmon, and S. Achord. 1983. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake Rivers, 1984. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H0034. 39 p. plus Appendices. (Available from the Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 88112-2097.)

Parsley, M. J., and L. G. Beckman. 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management 14:812-827.

Perry, R. W., and seven coauthors. 2003. Turbine survival and migration behavior of subyearling chinook salmon at McNary Dam, 2003. Draft Annual Report by the U.S. Geological Survey to the Bonneville Power Administration. 43 p. plus appendix.

Peery, C. A. and T. C. Bjornn. 2003. Water temperatures and passage of adult salmon and steelhead in the lower Snake River. U.S. Army Corps of Engineers, Technical Report 2003-2, 80 p. (Available online at http://www.cnr.uidaho.edu/coop/download.htm).

Plan for Analyzing and Testing Hypotheses (PATH). 1997. Review of dam passage survival and spill efficiency estimates for yearling chinook salmon in the Snake/Columbia system. PATH Hydro Work Group, Data Subcommittee. Draft #2 Memo dated June 23, 1997.

Plan for Analyzing and Testing Hypotheses (PATH). 1998. Preliminary decision analysis report on Snake River spring/summer chinook. 92 p. plus Appendixes. (Available from ESSA Technologies Ltd., 3rd Floor, 1765 West 8th Avenue, Vancouver, BC V6J 5C6.)

Piaskowski, R., P. Keniry, and T. Bjornn. 1998. Distribution and movements of northern squawfish and smallmouth bass during operation of a surface bypass and collection system for juvenile salmonids at Lower Granite Dam, WA. 1 p. Abstract *In* U.S. Army Corps of Engineers, Anadromous Fish Evaluation Program, 1998 Annual Research Review, U.S. Army Corps of Engineers, Portland, OR. (Available from U. S. Army Engineer District, Portland, OR.)

Ploskey, G. R., and T. J. Carlson. 1999. Comparison of hydroacoustic and net estimates of fish guideance efficiency of an extended submersible bar screen at John Day Dam. North American Journal of Fisheries Mangement 19:1066-1079.

Ploskey, G. R., and T. J. Carlson. 2004. Comparison of blade-strike modeling results with empirical data to identify effects and uncertainties. Report by Battelle Pacific National Laboratory to Dept. of Energy, dated March 2004.

Ploskey, G. R., M. E. Hanks, G. E. Johnson, W. T. Nagy, C. R. Shilt, L. R. Lawrence, D. S. Patterson, P. N. Johnson, J. Skalski. 1999. Hydroacoustic evaluation of juvenile salmon passage at The Dalles Dam: 1999. Draft Report, 63 p. plus Appendixes. (Available from U. S. Army Engineer District, Portland, OR 97208-2946.)

Ploskey, G. R., L. R. Lawrence, P. N. Johnson, W. T. Nagy, and M. C. Burczynski. 1998. Hydroacoustic evaluation of juvenile salmonid passage at Bonneville Dam including surface-collection simulations. Technical Report EL-98-4, 30 p. plus Appendixes. (Available from U. S. Army Engineer District, Portland, OR 97208-2946.)

Ploskey, G. R., W. T. Nagy, L. R.Lawrence, D.S.Patterson,C.R. Schilt, P.N. Johnson, J.R. Skalski. 1999. Hydroacoustic evaluation of juvenile salmonid passage through experimental routes at Bonneville Dam in 1998. Report to U.S. Army Corps of Engineers, 52 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

Ploskey, G., T. Poe, A. Giorgi, and G. Johnson. 2001. Synthesis of radio-telemetry, hydroacoustic, and survival studies of juvenile salmon at The Dalles Dam (1982-2000). U.S. Army Corps of Engineers. Contract No. DACW57-00-D-0009. (Available from U.S. Army Corps of Engineers, Portland, OR.)

Ploskey, G. R., C. R. Schilt, and seven others. 2000. Hydroacoustic evaluation of fish passage through Bonneville Dam in 2000. Technical report to U.S. Army Corps of Engineers, Portland District. 107 p.

Ploskey, G., C. Schilt, J. Kim, C. Escher, and J. Skalski. 2003. Hydroacoustic evaluation of fish passage through Bonneville Dam in 2002. Report to U.S. Army Corps of Engineers. Contract DE-AC06-76RLO1830. 121p. plus Appendices. (Available from Battelle's Northwest Pacific Division, P.O. Box 999, Richland, WA 99352.)

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, A. D. Cochran, T. K. Nation, J. M. Sprando, J. L. Schei, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2004. Behavior and survival of radio-tagged juvenile chinook salmon and steelhead relative to the performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Report to U.S Army Corps of Engineers, Contract Number W68SBV00104592. 92 p. plus Appendices.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, J. M. Sprando, G. T. George, N. S. Adams, and D. W. Rondorf. 2003. Behavior of radio-tagged juvenile chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, 2002. Report to the U.S. Army Corps of Engineers, Project No. W68SV00104592. 123 p. (Available from U.S. Geological Survey, Cook, WA 98605.)

Plumb, J. M., M. S. Novick, N. S. Adams, and D. W. Rondorf. 2002. Behavior of radio-tagged juvenile chinook salmon in the forebay of Lower Granite Dam relative to the 2000 surface bypass and behavioral guidance structure tests. Report to the U.S. Army Corps of Engineers, Project No. W685BV00104592. 50 p. (Available from U.S. Geological Survey, Cook, WA 98605).

Plumb, J. M., M. S. Novick, B. D. Liedtke, and N. S. Adams. 2001. Passage behavior of radio-tagged yearling chinook salmon and steelhead at Bonneville Dam associated with the surface bypass program, 1999. Report of Research to U.S. Army Corps of Engineers, Portland District, Portland, OR. (Available from U.S. Geological Survey) 30 p.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:405-420.

Prentice, E. F., T. A. Flagg, and C. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Am. F. Soc. Symposium 7: 317-322.

Prentice, E. F., T. A. Flagg, C. McCutcheon, and D. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Am. F. Soc. 7: 323-334.

Prentice, E. F., T. A. Flagg, C. McCutcheon, D. Brastow, and D. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT tagging. Am. F. Soc. Symposium 7: 335-340.

Quinn, T. P., S. Hodgson, and C. Peven. 1997. Temperature, flow, and migration of adult sockeye salmon (Oncorhynchus nerka) in the Columbia River. Can. J. Fish. Aquat. Sci. 54:1349-1360.

Rainey, W. S. 1997. Opportunity for discovery: a n important tool for assessment of surface collection technology potential for improving juvenile salmon passage at Columbia River dams. Electric Power and Research Institute Fish Passage Workshop, Milwaukee, Wisconsin, 7 May, 1997.

Ransom, B. H. 1997. Summary of spillway and sluiceway effectiveness in passing juvenile salmonids at Wanapum and Priest Rapids Dams from 1980-1996. Report to Grant County Public Utility District, Ephrata, WA.

Ransom, B., K. Kumagi, A. Birmingham, and P. Nealson. 1996. Effectiveness of a prototype surface flow attraction channel for passing juvenile salmon and steelhead trout at Wanapum Dam during the spring and summer 1995. Report to Grant County Public Utility District, Ephrata, WA.

Ransom, B. H. and B. D. McFadden. 1987. Hydroacoustic evaluation of juvenile fish passage at Lower Monumental Dam in 1987. U.S. Army Corps of Engineers, Walla Walla District, Contract DACW68-87-C-0043, 29 p. plus Appendixes.

Ransom, B. H., and D. A. Ouellette. 1988. Hydroacoustic evaluation of juvenile fish passage at Ice Harbor Dam in spring 1987. Report to U.S. Army Corps of Engineers, Walla Walla, WA. Contract DACW68-87-C-0043, 37 p. plus Appendixes.

Ransom, B. H., and A. E. Sullivan. 1989. Hydroacoustic evaluation of juvenile fish passage at Lower Monumental Dam in 1989. Report to U.S. Army Corps of Engineers, Walla Walla, Washington, Contract DACW68-89-C-0021, 35 p. plus Appendixes.

Raymond, H. L. 1964. Effects of dams on the upstream migration rates and timing of Columbia River salmonids. Report for Fish Passage Research Program of the Bureau of Commercial Fisheries. 5 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Raymond, H. L. 1979. Effects if dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Am. F. Soc. 108:505-529.

Raymond, H. L., and C. W. Sims. 1980. Assessment of smolt migration and passage enhancement studies for 1979. Report to U.S. Army Corps of Engineers, 48 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Ross, C. V. 1983. Evaluation of adult fish passage at Bonneville Dam, 1982. 59 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

RMC (RMC Environmental Services), Mid-Columbia Consulting, and J. R. Skalski. 1994. Turbine passage survival of spring migrant chinook salmon (*Oncorhynchus tshawytscha*) at Lower Granite Dam, Snake River, Washington. Report to U. S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Ruggles, C. P., and D. G. Murray. 1983. A review of fish response to spillways. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1172. 31 p.

R 2 Resource Consultants, Inc. 1997. Annotated bibliography of literature regarding mechanical injury with emphasis on effects from spillways and stilling basins. Contract DACW57-96-D-0007, Task Order No. 03. Report to Portland District, U. S. Army Corps of Engineers. (Available from U. S. Army Corps of Engineers, P.O. Box 2946, Portland, OR. USA. 97208)

Sandford, B. P, and S. G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River Basin salmonids, 1990-1997. Journal of Agricultural Biological and Environmental Statistics 7:243-263.

Schaller, H. A., C. E. Petrosky, and O. P. Langness. 1999. Contrasting patterns of productivity and survival rates for stream-type chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia Rivers. Can. J. Aquat. Sci. 56:1031-1045.

Schilt, C., G. Ploskey, J. Skalski, J. Kim, C. Escher, D. Patterson, K. Bouchard, P. Johnson, W. Nagy, and L. Lawrence. 2002. Hydroacoustic evaluation of fish passage through Bonneville Dam in 2002. Abstract, U. S. Army Corps of Engineers Anadromous Fish Evaluation Program, Annual Review 2002, Portland, OR.

Schoeneman, D. E., R. T. Pressey, and C. O. Junge, Jr. 1961. Mortalities of downstream migrant salmon at McNary Dam. Trans. Am. Fish. Soc. 90:58-72.

Schrank, B. P., B. A. Ryan, and E. M. Dawley. 1997. Evaluation of the effects of dissolved gas supersaturation on fish and invertebrates in Priest Rapids Reservoir and downstream from Bonneville and Ice Harbor Dams, 1995. Report to U.S. Army Corps of Engineers, Contract E96940029, 45 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Schrank, B. P., B. A. Ryan, and E. M. Dawley. 1998. Effects of dissolved gas supersaturation on fish residing in the Snake and Columbia Rivers, 1996. Report to Bonneville Power Administration, Contract 96-BI-93605, 58 p plus Appendixes. (Available from Bonneville Power Administration, Portland OR 97208.)

Schreck, C. B. and I. Knoebl. 1997. Development of design criteria to improve wet separator efficiency and reduce delay of fish in areas of accelerating flow (Objective 4: Evaluation of modified barge exits). Draft Project Report to U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

Selye, H. 1956. The stress of life. McGraw-Hill Book Co., New York, NY. 324 p.

Sharpe, C. S., D. A. Thompson, H. L. Blankenship, and C. B. Schreck. Effects of handling and tagging procedures on physiological stress responses in juvenile chinook salmon. 1998. Prog. Fish-Cult. 60:81-87.

Sheer, M. B., G.S. Holmberg, R. S. Shively, T. P. King, C. N. Frost, H. C. Hansel, T. M. Martinelli, and T. P. Poe. 1997. Movement, distribution, and passage behavior of radio-tagged juvenile chinook salmon in John Day and The Dalles Dam forebays, 1995. Report to U.S. Army Corps of Engineers, Portland, OR, 42 p. plus Appendixes (Available from U.S. Army Corps of Engineers, Portland, OR 97208.)

Shively, R. S., T. P. Poe, M. B. Sheer, and R. Peters. 1996. Criteria for reducing predation by northern squawfish near juvenile salmonid bypass outfalls at Columbia River dams. Regul. Rivers Res. & Manage. 12: 493-500.

Sims, C. W., and F. J. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979. NMFS Coastal Zone and Estuarine Studies Division. Report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0038, 31 p. plus Appendix.

Skalski, J. R., G. E. Johnson, C. M. Sullivan, E. A. Kudera, and M. W. Erho. 1996. Statistical evaluation of turbine bypass efficiency at Wells Dam on the Columbia River, Washington. Can. J. Fish. Aquat. Sci. 53:2188-2198.

Skalski, J. R., D. Mathur, and P. G. Heisey. 2002. Effects of turbine operating efficiency on smolt passage survival. N. Am. J. Fish. Manage. 22:1193-2000.

Smith, H. A. 1974. Spillway redesign abates gas supersaturation in Columbia River. Civil Engineering-ASCE, Sept., 4 p.

Smith, S. G. 1997. Fish guidance efficiency (FGE) for natural and hatchery spring/summer chinook salmon: information provided by PIT-tag data 1993-1997. Memo dated 29 July 1997. 6 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Smith, S. G., J. R. Skalski, and A. E. Giorgi. 1993. Statistical evaluation of travel time estimation based on data from freeze-branded chinook salmon on the Snake River, 1982-1990. Report to Bonneville Power Administration. Portland, OR. 97208. Contract DE-B179-91BP35885, 95 p. plus Appendixes. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Smith, S. G., W. D. Muir, E. E. Hockersmith, S. Achord, M. B. Eppard, T. E. Ruehle, and J. G. Williams. 1998. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1996. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, 197 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Smith, S. G., W. D. Muir, R. W. Zabel, D. M. Marsh, R. A. McNatt, J. G. Williams, and J. R. Skalski. 2003a. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2003. In review. Report to the Bonneville Power Administration, Project 199302900.

Smith, S. G., W. D. Muir, E. E. Hockersmith, and R. W. Zabel. 2003b. Influence of river conditions on survival and travel time of Snake River subyearling fall chinook salmon. N. Am. J. Fish. Manage. 23:939-961.

Smith, S. G., W. D. Muir, G. A. Axel, R. W. Zabel, J. G. Williams. 2000. Survival estimates for the passage of juvenile salmonids through Snake and Columbia River dams and reservoirs, 1999. Annual Report to Bonneville Power Administration, Project 199302900. 75 p.

Snelling, J. C., and S. A. Mattson. 1998. Behavior and fate of juvenile salmonids entering the tailwaters of The Dalles Dam via spill. Report to U.S. Army Corps of Engineers, Portland District, Portland, OR, 38 p. plus Appendixes.

Spurgeon, W., P. Wagner, M. Price, and S. Lind. 1998. 1998 Juvenile fish collection and bypass report, Lower Monumental Dam juvenile fish facility. 25 p. plus Appendix. (Available from U. S. Army Corps of Engineers, Walla Walla,WA.)

Steig, T. W. 1994. Review of spring and summer spill effectiveness for juvenile salmon and steelhead at various Columbia and Snake River dams, 1983-1992. Thirteenth Annual Symposium of the North American Lake Management Society, Seattle, Washington, November 29 - December 4, 1993. Lake and Reservoir Management 9(1):154-162.

Steig, T. W., and R. Adeniyi. 1997. Hydroacoustic evaluation of the fish passage through Units 1-11, Spillways 3-5, and the surface collector at Rocky Reach Dam during the spring and summer of 1996. Report to Chelan County Public Utility District, Wenatchee, WA. 53 p. plus Appendixes.

Steig, T. W., and W. R. Johnson. 1986. Hydroacoustic assessment of downstream migrating salmonids at The Dalles Dam in spring and summer 1985. Report to Bonneville Power Administration. Contract DE-AC79-85 BP23174, 56 p. plus Appendixes.

Strange, R. J., C. B. Schreck, and R. D. Ewing. 1978. Cortisol concentrations in confined juvenile chinook salmon (*Oncorhynchus tshawytscha*). Trans. Am. Fish. Soc. 107(6):812-819.

Stuehrenberg, L.and K. Liscom. 1983. Radio tracking of juvenile salmonids in John Day reservoir, 1982.. 21 p. plus Appendix. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Stuehrenberg, L., K. Liscom, and G. Monan. 1978. A study of apparent losses of chinook salmon and steelhead based on count discrepancies between dams on the Columbia and Snake Rivers, 1967 - 1968. 49 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Stuehrenberg, L. C., G. A. Swan, L. K. Timme, P. A. Ocker, M. B. Eppard, R. N. Iwamoto, B.L. Iverson, and B. P. Sandford. 1995. Migrational characteristics of adult spring, summer, and fall chinook salmon passing through reservoirs and dams of the Mid-Columbia River. Report to Mid-Columbia Public Utility Districts, 79 p. plus Appendixes. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Sverdrup Corporation. 1995. A review of the 1981 to 1992 hydroacoustic studies of the Wells Dam juvenile fish bypass system. Report to Grant County Public Utility District, Ephrata, WA. 19 p. plus Appendix.

Swan, G., M. Eppard, E. Hockersmith, B. Sandford, and R. Iwanmoto. 1996. Juvenile radio telemetry study: Ice Harbor Dam, 1995. Report to U.S. Army Corps of Engineers, Walla Walla District.

Swan, G. A., L. K. Timme, R. N. Iwamoto, L. C. Stuehrenberg, E. E. Hockersmith, B. L. Iverson,and B. P. Sandford. 1994. Wells Dam radio-telemetry study, 1992. Report to Douglas County Public Utility District, East Wenatchee, WA, 64 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Swan, G. A., R. F. Krcma, and W. E. Farr. 1979. Dipbasket for collecting juvenile salmon and trout in gatewells at hydroelectric dams. Prog. Fish-Cult. 41(1):48-49.

Swan, G. A., B. H. Monk, J. G. Williams, and B. P. Sandford. 1990. Fish guidance efficiency of submersible traveling screens at Lower Granite Dam - 1998. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 25 p. plus Appendixes. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Tiffan, K. F., C. A. Haskell, J. A. Heinz, M. G. Mesa, and D. W. Rondorf. 2003a. Water temperature effects on fall chinook salmon in the Snake and Columbia Rivers, 2001. Annual report of the U.S. Geological Survey to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Tiffan, K. F., D. W. Rondorf, and W. P. Connor. 2003b. Post-release attributes and survival of hatchery and natural fall chinook salmon in the Snake River. Bonneville Power Administration. Available www.efw.bpa.gov/Environment/EW/EWP/DOCS/REPORTS/GENERAL/I00005362-1.pdf (October 2003).

Turner, A. R., J. R. Kuskie, K. E. Kostow. 1983. Evaluation of adult fish passage at Little Goose and Lower Granite Dams, 1981. U.S. Army Corps of Engineers, Portland District. 84 p. plus appendices.

Turner, A. R., J. R. Kuskie, K. E. Kostow. 1984. Evaluations of adult fish passage at Ice Harbor and Lower Monumental Dams, 1982. U.S. Army Corps of Engineers, Portland District. 87 p.

U.S. Army Corps of Engineers (COE). 1998d. John Day Lock and Dam surface bypass spillway, Feature Design Memorandum 52. 67 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland OR.)

U.S. Army Corps of Engineers (COE). 1994. Lower Granite and Little Goose Locks and Dams: adult collection channel velocity measurements; 25 January 1994. Unpublished report to Army Corps of Engineers. 7 p. (Available from U.S. Army Corps of Engineers, Walla Walla, WA.)

U.S. Army Corps of Engineers (COE). 1995a. Bonneville Second Powerhouse, juvenile fish sampling & monitoring facility, Feature Design Memorandum 43, Portland District, Portland OR, 51 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corp of Engineers (COE). 1995b. Proceedings, turbine fish passage survival workshop. 212 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1996a. Bonneville Second Powerhouse, downstream migrant system improvements, 90% Review, Supplement 6 to Design Memorandum 9, Portland District, Portland OR, 50 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1996b. Dissolved Gas Abatement, Phase I, Technical Report. North Pacific Division, Portland, OR, 70 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1997. Bonneville Second Powerhouse juvenile fish monitoring facility, Feature Design Memorandum 9, Supplement 8, Portland District, Portland OR, 70 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1998a. Dissolved Gas Abatement Study; Phase II, 60% Draft Report. Portland District, Portland, OR, 414 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1998b. 1998 Total Dissolved Gas Annual Report. 29 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1998c. Turbine Passage Survival Program, 1997 Annual Report. Northwestern Division, Portland, OR. 49 p. plus Appendixes.

U.S. Army Corps of Engineers (COE). 1999. Bonneville First Powerhouse, juvenile bypass system improvements, Supplement 2 to Design Memorandum 37, Portland District, Portland OR, 172 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

U.S. Army Corps of Engineers (COE). 1999e. Travel Time Summary Table. Technical Management Team; Internet Webpage: http://www.nwd~wc.usace.army.mil/TMT/1999/current/pit-flow/travtime/seltab.html.

U.S. Army Corps of Engineers (COE), ASCI Inc., and Bioanalysts. 1999f. Hydroacoustics evaluation of downstream migrant fish passage at The Dalles Dam in 1999 - Preliminary Report.

U. S. Army Corps of Engineers (COE). 2003. Turbine survival Program (TSP) Phase I report, 1997-2003. Draft report by the U.S. Army Corps of Engineers, Portland District, dated November 2003, 220 p.

U.S. Army Corps of Engineers (COE). 2004. Fish Passage Plan for Corps of Engineers Projects. Northwestern Division, Portland, OR, 270 p. plus Appendixes. (Available from U.S. Army Corps of Engineers, Portland, OR.)

WAC (Washington Administrative Code). 1992. Water quality standards for surface waters of the state of Washington. Chapter 173-201A WAC.

Wagner, E., and P. Ingram. 1973. Evaluation of fish facilities and passage at Foster and Green Peter Dams on the South Santiam River drainage in Oregon. Report by the Fish Commission of Oregon to the U.S. Army Corps of Engineers, Portland District, Contract No. DACW57-68-C-0013, 81 p.

Ward, D. L., J. H. Peterson, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Trans. Am. Fish. Soc. 124:321-334.

Warren, J.J., and L.G. Beckman. 1993. Fishway use by white sturgeon on the Columbia River. Washington Sea Grant Program, Seattle, Washington. WSG-AS 93-02.

Wedemeyer, G. A. 1976. Physiological response of juvenile coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*Salmo gairdneri*) to handling and crowding stress in intensive fish culture. J. Fish. Res. Board Can. 33:2699-2702.

Weiland, M. A., and T. J. Carlson. 2003. Technologies for evaluating fish passage through turbines. Report by Battelle Pacific National Laboratory to Dept. of Energy, October 2003, 58 p. plus appendices.

Weitkamp, D.E. 1976. Dissolved Gas Supersaturation: Live-Cage Bioassays at Rock Island Dam, Washington. In: Gas Bubble Disease (proceedings of Gas Bubble Disease Workshop), ed. by D.H. Fickeisen and M.J. Schneider. U.S. Department of Commerce, Technology Information Service, CONF-741033. p. 24-36.

Weitkamp, D. E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Trans. Am. Fish. Soc. 109:659-702.

Wertheimer, R. H., J. T. Dalen, and P. L. Madson. 2001. Evaluation of steelhead kelt passage routes at Bonneville Dam, 2000. Report prepared by U.S. Army Corps of Engineers, Portland District Fisheries Field Unit, Bonneville Lock and Dam, Cascade Locks, OR.

Wertheimer, R. H., J. T. Dalen, and P. L. Madson. 2002. Evaluation of steelhead kelt project abundance, condition, passage, and conversion rates, 2001. Report prepared by U.S. Army Corps of Engineers, Portland District Fisheries Field Unit, Bonneville Lock and Dam, Cascade Locks, OR.

Wertheimer, R. H., P. L. Madson, and M. R. Jonas. 2003. Abstract: Synthesis of the project abundance, passage, conversion, and return Rates from steelhead kelts passing lower Columbia River dams (2000-2003). Anadromous Fish Evaluation Program Annual Review, 2003. U.S. Army Corps of Engineers, Walla Walla District.

Westgard, R. L. 1964. Physical and biological aspects of gas bubble disease in impounded adult chinook salmon at McNary spawning channel. Trans. Am. Fish. Soc. 93:306-309.

Whitney, R. R., L. Calvin, M. Erho, and C. Coutant. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River Basin: development, installation, and evaluation. U.S. Department of Energy, Northwest Power Planning Council, Portland, Oregon. Report 97-15. 101 p.

Whitt, C. R. 1954. The age, growth, and migration of steelhead trout in the Clearwater River, Idaho. M.S. thesis, University of Idaho, Moscow, ID.

Williams, J. G., and G. M. Matthews. 1995. A review of flow and survival relationships for spring and summer chinook salmon, *Oncorhynchus tshawytscha*, from the Snake River basin. Fishery Bulletin 93:732-740.

Williams, J. G., M. H. Gessel, B. P. Sandford, and J. J. Vella. 1996. Evaluation of factors affecting juvenile chinook salmon fish guidance efficiency. Report to U.S. Army Corps of Engineers, Walla Walla District, Contract E86910059, 35 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Williams, J. G., S. S. Smith, W. D. Muir. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia River hydropower system, 1996 to 1980 and 1993 to 1999. N. Amer. J. Fish. Manage. 21:310-317.

Williams, J. G., S. G. Smith, W. D. Muir, B. P. Sandford, S. Achord, R. McNatt, D. M. Marsh, R. W. Zabel, and M. D. Scheuerell. (In prep). Effects of the Federal Columbia River Power System on salmon populations. NOAA Fisheries Technical Memorandum.

Willis, C. F. 1982. Indexing of juvenile salmonids migrating past The Dalles Dam, 1982. Report to U.S. Army Corps of Engineers, Portland, OR, Contract DACW57-78-C-0056, 37 p. plus Appendixes. (Available from Oregon Department of Fish and Wildlife, Portland, OR.)

Willis, C. F. and B. L. Uremovich. 1981. Evaluation of the ice and trash sluiceway at Bonneville Dam as a bypass system for juvenile salmonids, 1981. Oregon Department of Fish and Wildlife, Portland, OR. Annual progress report prepared for the National Marine Fisheries Service, Contract No. 81-ABC-00173, 34 p. plus appendices.

Wilson, J., A. Giorgi, and L. Stuehrenberg. 1991. A method for estimating spill effectiveness for passing juvenile salmon and its application at Lower Granite Dam on the Snake River. Can. J. Fish. Aquat. Sci. 48:1872-1876.

Wittinger, R., and C. Polinsky. 2002. Biological test turbine operating conditions Units 9, 4. Report prepared for U.S. Army Corps of Engineers, Walla Walla WA, from U. S. Army Corps of Engineers Hydroelectric Design Center.

Wright, R. J., L. Johnson, and T. H. Schadt. 1986. Hydroacoustic evaluation of juvenile fish passage at Lower Monumental Dam in spring 1986. Report to U.S. Army Corps of Engineers, Walla Walla , WA, Contract DACW68-86-C-0038, 61 p. plus Appendixes.

Zabel, R. W. and J. G. Williams. 2000. Comments on “contrasting patterns of productivity and survival rates for stream-type chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia Rivers” by Schaller et al. (1999). Can. J. Fish. Aquat. Sci. 57:1739-1741.

Zabel, R. W., S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2001. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2000. Annual Report to Bonneville Power Administration, Project No. 199302900. 60 p.

Zabel. R. J., and J. G. Williams. 2002. Selective mortality in chinook salmon: What is the role of human disturbances? Ecological Applications 12:173-183.

Zabel, R., J. Williams, S. Smith, W. Muir, D. Marsh. 2002. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs. Project No. 1993-02900, 143 electronic pages. (BPA Report DOE/BP-00004922-1)

Zabel, R. W., T. Wagner, J. L. Congelton, S. G. Smith, and J. G. Williams. In review. Estimating population survival and selection for phenotypic traits despite confounding behavioral variability. Ecological Applications.